D.0 Technical Approach for Nutrient TMDL Devlopment

D.1 General

In general, a scientifically justifiable TMDL for a specific waterbody can only be developed based on a quantitative understanding of the system. In practice, water quality modeling offers a feasible tool to establish such a quantitative understanding. A water quality model that is customized to a specific water system can simulate the major physical, chemical, and biological process that occur in the system, providing quantitative relationships between the water quality response and the variation of external force functions, including pollutant loading conditions and hydrologic and atmospheric conditions.

A modeling framework was developed regarding the goal of this study and consideration of specific characteristics of the Wissahickon Creek basin. Following the data analysis of the system, the critical condition for DO impairment was identified to be the low-flow condition associated with high nutrient concentrations. Therefore, a steady-state modeling scheme was deemed as a proper configuration for developing TMDLs for the Wissahickon Creek basin.

A hydrodynamic and water quality model of the Wissahickon Creek system (see Figure D-1) were developed for use in nutrient TMDL calculations. The modeling framework used in this study consisted of two major components: a hydrodynamic model developed using the computational framework of Environmental Fluid Dynamics Code (EFDC), and a nutrient and DO interaction simulation model developed using the Water Quality Simulation Program (WASP) for eutrophication (EUTRO). A linking interface has been developed to allow a smooth communication between the two model components. To allow simulation of diurnal DO fluctuation, a periphyton routine, which was incorporated into the standard EUTRO module by the Hydraulic & Water Resources Engineers, Inc. (HWRE), has been modified to allow a more realistic representation of the interaction between dissolved oxygen and biological activities.

The model segments cover the main channel of Wissahickon Creek as well as other 303(d) listed tributaries including Pine Run, Sandy Run, Trewellyn Creek, and Lorraine Run. The model consists of 115 computational grid cells with non-uniform dimensions. The hydrodynamic model was calibrated using the travel-of-time data obtained from a dye study provided by PA DEP, and the water quality model was calibrated using the water quality data collected in a 2002 survey conducted by PA DEP. This technical report briefly describes the technical facets of the modeling study and TMDL development for the Wissahickon Creek basin.

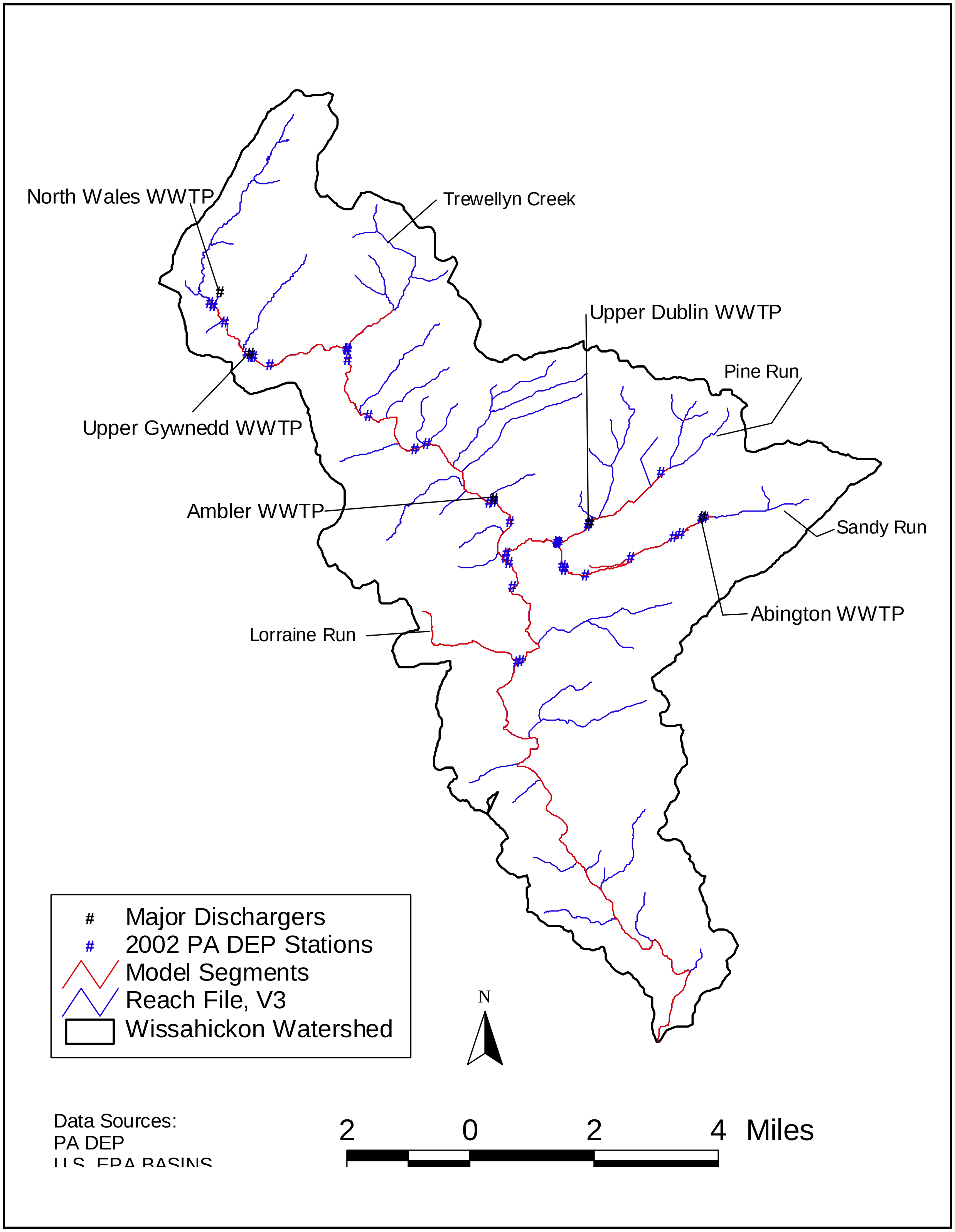

Figure D-1. Wissahickon Creek model extent

D.2 EFDC Hydrodynamic Model

D.2.1 Model Background

The Environmental Fluid Dynamics Code (EFDC) is a general purpose modeling package for simulating three-dimensional flow, transport, and biogeochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model was originally developed by Hamrick (1992a) at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. In addition to hydrodynamic, salinity, and temperature transport simulation capabilities, EFDC is capable of simulating cohesive and noncohesive sediment transport, near field and far field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants in the water and sediment phases, and the transport and fate of various life stages of finfish and shellfish. Special enhancements to the hydrodynamic portion of the code, including vegetation resistance, drying and wetting, hydraulic structure representation, wave-current boundary layer interaction, and wave-induced currents, allow refined modeling of wetland marsh systems, controlled flow systems, and nearshore wave induced currents and sediment transport. The EFDC model has been extensively tested and documented for more than 20 modeling studies. The model is presently being used by a number of organizations including universities, governmental agencies, and environmental consulting firms.

The structure of the EFDC model includes four major modules: (1) a hydrodynamic model, (2) a water quality model, (3) a sediment transport model, and (4) a toxics model. The EFDC hydrodynamic model itself, which was used for this study, is composed of six transport modules including dynamics, dye, temperature, salinity, near field plume, and drifter (see Figure D-2).

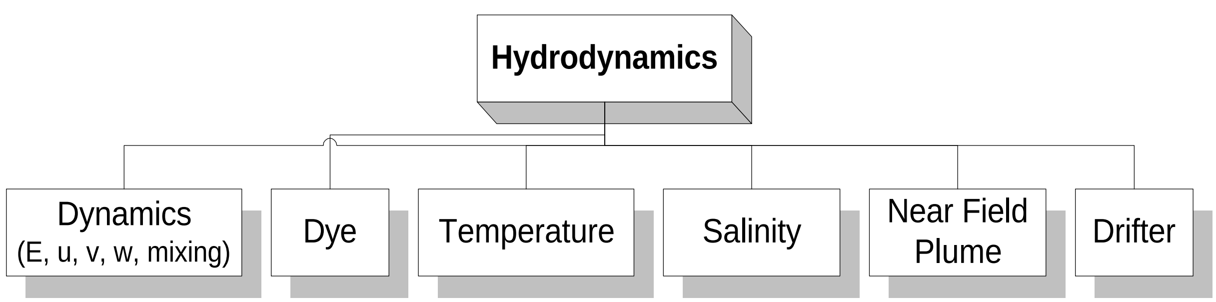

Figure D-2. Structure of the EFDC hydrodynamic model.

D.2.2 Description of Solution Methods

The computational schemes in the EFDC model were equivalent to the widely used Blumberg-Mellor model in many aspects. The EFDC model used a stretched or sigma vertical coordinate and Cartesian, or curvilinear, orthogonal horizontal coordinates. The EFDC employed a second order accurate spatial finite differencing on a staggered or C grid to solve the equations of momentum, while the time integration was implemented using a second order accurate three-time level, finite difference scheme with an internal-external mode splitting procedure to separate the internal shear or baroclinic mode from the external free surface gravity wave or barotropic mode. The external mode solution was semi-implicit and simultaneously computed the two-dimensional (2-D) surface elevation field by a preconditioned conjugate gradient procedure. The external solution was completed by the calculation of the depth-averaged barotropic velocities using the new surface elevation field. The model's semi-implicit external solution allowed large time steps that were constrained only by the stability criteria of the explicit central difference or high order upwind advection scheme (Smolarkiewicz and Margolin 1993) used for the nonlinear accelerations. Horizontal boundary conditions for the external mode solution included options for simultaneously specifying the surface elevation only, the characteristic of an incoming wave (Bennett and McIntosh 1982), free radiation of an outgoing wave (Bennett 1976; Blumberg and Kantha 1985), or the normal volumetric flux on arbitrary portions of the boundary. The EFDC model's internal momentum equation solution, at the same time step as the external solution, was implicit with respect to vertical diffusion. The internal solution of the momentum equations was in terms of the vertical profile of shear stress and velocity shear, which resulted in the simplest and most accurate form of the baroclinic pressure gradients and eliminates the over-determined character of alternate internal mode formulations. Time splitting inherent in the three-time-level scheme was controlled by periodic insertion of a second-order accurate two-time-level trapezoidal step.

The EFDC model implemented a second-order, accurate in space and time, mass conservation, fractional step solution scheme for the Eulerian transport equations for salinity, temperature, and other constituents. The transport equations were temporally integrated at the same time step or twice the time step of the momentum equation solution. The advective step of the transport solution used either the central difference scheme used in the Blumberg-Mellor model or a hierarchy of positive definite upwind difference schemes. The highest accuracy upwind scheme, second order accurate in space and time, was based on a flux-corrected transport version Smolarkiewicz's multidimensional positive-definite advection transport algorithm (Smolarkiewicz and Clark, 1986; Smolarkiewicz and Grabowski 1990), which was monotonic and minimizes numerical diffusion. The horizontal diffusion step was explicit in time, whereas the vertical diffusion step was implicit. Horizontal boundary conditions included material inflow concentrations, upwind outflow, and a damping relaxation specification of climatological boundary concentration.

D.2.3 Linkage With WASP Model

The existing EFDC modeling package includes a variety of linkage ports with different versions of WASP. In this study, the linkage port with WASP5 was modified to enhance the capability of incorporating boundary flows as well as handling one-dimensional attachment of tributaries using artificial joint segments. The linkage port was able to generate three sections of WASP master input files in addition to a hydrodynamic file. The hydrodynamic file was saved in a form conforming to the format requirement of WASP. The flow information stored in the hydrodynamic file allowed the WASP model to provide a mass transport calculation with time variable circulation pattern. The linkage interface was tested and found to satisfy the criterion of mass conservation.

D.3 WASP/EUTRO Modeling Framework

D.3.1 General

The Water Quality Analysis Simulation Program (WASP) Eutrophication (EUTRO) is a general modeling framework aimed at simulating fate and transport of nutrients and corresponding biological response in any receiving water bodies in any spatial dimensions (Ambrose et al., 1988). WASP/EUTRO allows users to interpret and predict water quality responses to natural and man-made impacts for water quality management decision making. WASP is developed as a dynamic finite segment modeling system for aquatic systems, including both the water column and the underlying sediment column.   The basic program of WASP represents the time variable advection, dispersion, point and distributed mass loading, and boundary exchanges of mass. The EUTRO module represent the reaction kinetics of nutrients, organic matters and dissolved oxygen. The combination of the mass transport (WASP) and bio-chemical reaction (EUTRO) results in an integrated modeling framework for in-water process of conventional pollutants.

The reactions involved in the standard WASP/EUTRO5 can be considered as four interacting systems: phytoplankton kinetics, the phosphorus cycle, the nitrogen cycle, and the dissolved oxygen balance. The standard EUTRO5 module consists of eight constituent systems, including Ammonium (NH_4^+), Nitrite/Nitrate (NO_2^-/NO_3^-), Ortho-phosphate (PO_4), Chlorophyll-a (CHLA), Carbonaceous Biochemical Oxygen Demand (CBOD), Dissolved Oxygen (DO), Organic Phosphorus (OP), and Organic Nitrogen (ON). The kinetics structure and interactions between these systems are illustrated in Figure D-3.

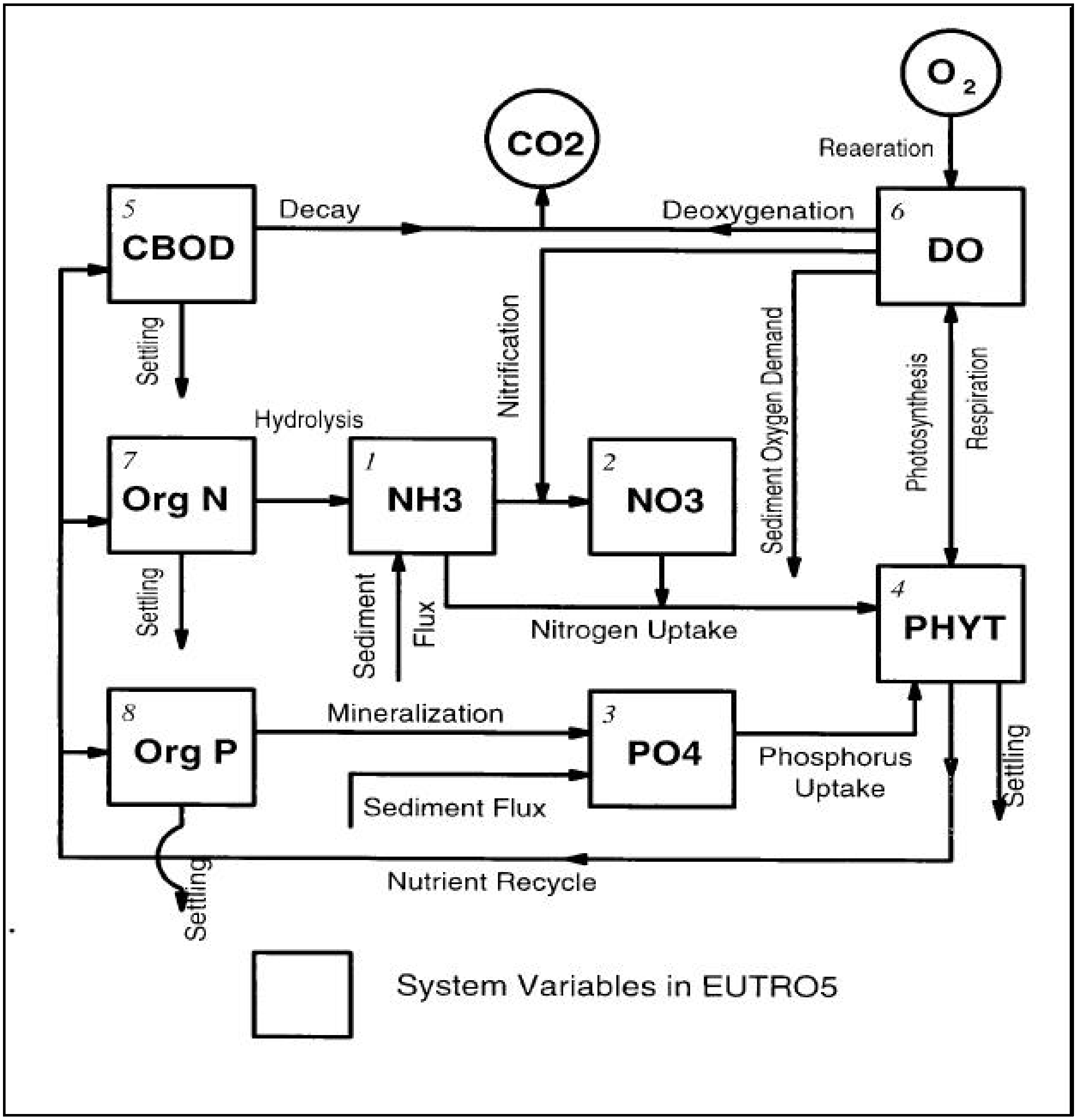

Figure D-3. Kinetic Structure in Standard WASP/EUTRO Model

D.3.2 Model Modifications

Past investigation shows that periphyton could be a significant contributor to the diurnal DO fluctuation in the Wissahickon Creek basin. The standard WASP/EUTRO does not have a system compartment for periphyton, thus a modified version of WASP/EUTRO by the HWRE was used as the basis of modeling. In the HWRE's WASP/EUTRO version, periphyton was incorporated into the model system as the NO.9 system compartment. The model was capable of representing major periphyton kinetics including growth, photosynthesis, respiration, and grazing/non-grazing associated death. Similar to phytoplankton, the metabolism of periphyton is affected by environmental conditions such as temperature, nutrient limitation, and light intensity.

The HWRE's WASP/EUTRO was in general a suitable framework for the Wissahickon modeling. However, the model code suffered several problems in that it isolated the compartment of DO and periphyton when calculating diurnal DO swing, and its diurnal DO simulation module require several environmental parameters which required significant data analysis and preparation effort outside of the scope of this study. In addition, the model did not consider the ecological carrying capacity, thus periphyton population could grow to unreasonable high levels when light and nutrients are in abundant supply.

A modification to the code was accomplished to remedy the problem with periphyton and DO interaction. In addition, a simplified diurnal simulation module was added to the EUTRO code to allow a reasonably accurate representation of the DO fluctuation in the receiving water. The simplified diurnal module used average radiation intensity to govern the algal/periphyton dynamics during daylight hours, and likewise used specific environment factors to restrict algal/periphyton growth during the night. The modified model was capable of simulating time variable DO with hourly resolution (or higher resolution if required), and the daily average, minimum, and maximum DO concentration were then estimated.

D.4 Model Configuration and Calibration

Two models were used to model hydrodynamics (EFDC) and water quality (WASP) of the Wissahickon Creek basin, with each model configured and calibrated separately.

D.4.1 Hydrodynamic Model

This section outlines the configuration and calibration of the EFDC model used for hydrodynamic modeling of the Wissahickon Creek basin.

D.4.1.a Segmentation

Wissahickon Creek and its tributaries are narrow and shallow, suggesting a one-dimensional configuration for representation of the system. The geometry data used for segmentation were collected by PA DEP in Summer 2002. The width and depth between any two survey cross-sections were obtained through linear interpolation. Considering the distribution of point sources and the goal of the modeling study, Wissahickon Creek and its four major tributaries were divided into 115 computational cells. The model files describing the bathymetry were generated using a pre-processor developed specifically for this study.

D.4.1.b Flow Balance

PA DEP collected streamflow data during the period from July 11, 2002 to August 11, 2002. In addition, major dischargers provided time variable discharge data for the same period. There are two USGS stations located in the Wissahickon Creek basin: one at the mouth of the Wissahickon Creek mainstem (USGS 01474000), and the other on Wissahickon Creek at Fort Washington (USGS01473900). Since configuration of the hydrodynamic model required information about flow rates at the upper stream boundaries, a flow balance calculation was implemented to estimate those streamflows at locations not directly measured by PA DEP.

The flow balance calculation was performed based on an assumption of stationary stochastic process. For the low-flow season during which the PA DEP survey was conducted, it is reasonable to assume that the channel flow is not under the impact of stormflows. Therefore, streamflows were assumed to be governed by a stationary stochastic process, where the fluctuation of streamflow between days during the low-flow season was only controlled by stochastic factors. The assumption of stationary stochastic process has been widely used in hydrological time series analysis, and is generally considered valid for a hydrological unit of which the environmental conditions are relatively stable (Zou, 1999). With this assumption, the data gaps in the USGS data can be regenerated using a random number generator, forming the basis of further flow balance calculation.

The flow balance in this study is obtained through the following multi-step process:

(1) Calculate the baseflow rate of the downstream portion of Wissahickon Creek:

Q(DS)=Q(USGS014000)-Q(USGS01473900)-Q(Lorraine_run_obs)

Where, Q(DS) is the combined flow rate from the small tributaries along the downstream portion of WissahickonCreek; Q(USGS0149000) and Q(USGS01473900) are the USGS gage flow at the corresponding gage stations, and Q(Lorraine_run_obs) is the observed flow rate of Lorraine Run on August 7, 2002.

The value for Q(DS) is calculated as 1.71 cfs. The baseflow from the downstream portion of Wissahickon Creek is assumed constant during the low-flow season.. Thus, the value 1.71 cfs is used for all the days during the survey period.

(2) Distribute the downstream baseflow to 10 tributaries
The calculated 1.71 cfs of flow is distributed to inflow points at the confluence of 10 tributaries based on area of each subwatershed.

(3) Calculate flow from Lorraine Run for the dates other than the sampling day
The flow rate from Loraine Run is calculated based on a flow balance relationship:

Q(Lorraine_Run)=Q(USGS0147000)-Q(USGS01473900)-Q(DS)

(4) Calulate flows for Pine Run and Sandy Run
Headwater flow rates for Sandy Run and Pine run were estimated directly from instream monitoring data and data provided by dischargers using the following relationships and were based on availability of data. There were no sufficient streamflow data collected upstream of Abington STP on Sandy Run.

Q(Pine)=Q(monitored upstream of Upper Dublin)

Q(Sandy)=Q(monitored downstream of Abington) - Q(Abington)

(5) Calculate net flow from background flow at the area above USGS01473900 as:

Qnet=Q(USGS01473900) - Q(Abington)-Q(Ambler) - Q(Upper Dublin) - Q(Upper Gwynedd) - Q(North Wales)

When the calculated Qnet is a negative number, then a background flow of 0.8 cfs is assigned to headwater portions of the model (upstream of STPs).

(6) The headwater flow of Wissahickon Creek is specified as 0.1 cfs based on the information provided by the PADEP for daily average releases from stormwater detention facilities operated by Merck & Co., Inc.

(7) Determine flow ratios for each upsteam location to the mouth of Wissahcikon Creek USGS gage 0147000.

(8) Distribute flow for the dates other than the sampling date using the ratios of flow established in Steps 1 through 7 to flows measured at USGS gage 0147000 at the mouth of Wissahicikon Creek. For the dates with negative Qnet, a background flow of 0.2 cfs is specified. Following this

procedure, the flow rate at each upstream location was estimated for 7Q10 conditions (see Section A.5.1).

D.4.1.c Other Forcing Data

In addition to flow data, the EFDC model also requires atmospheric boundary forcing data such as solar radiation, wind shear stress, and air temperature to drive the hydrodynamic simulation. Since Wissahickon Creek is very narrow and shallow, the atmospheric force function were not expected to have significant impact on the water circulation pattern. In spite of this condition, real weather data at Allentown, PA, were downloaded from the NOAA website to form the atmospheric boundary condition in the model.

D.4.1.e Calibration

In 2002, PA DEP conducted a dye study to analyze the time of travel in Wissahickon Creek, Pine Run, and Sandy Run during the low flow season. The information obtained in the dye study was used to calibrate the hydrodynamic model. The dye study conducted by the PADEP covers a range of start-end location pairs or “schemes.” Four schemes successfully captured peaks of dye concentrations to provide sufficient information regarding time of travel. Time-of-travel data was available for Pine Run, Sandy Run, and two segments of Wissahickon Creek. Locations of schemes are depicted in Figure D-4.

After the locations of the start and end points of each dye release scheme were determined, the configuration of the EFDC model was modified such that the velocity at the model segments between start and end points of each dye release scheme were used to calibrate the model. Given the velocity and length of each segment, the time of travel was calculated and compared with the measured data in the dye study. If the model-simulated time of travel deviates significantly from the observed data, the model’s bottom friction coefficient and bathymetry was adjusted within a reasonable range. This calibration process continued until an acceptable agreement was achieved between the model and observed data. Figure D-5 shows the model-data comparison for hydrodynamic calibration. As shown, the time of travel simulated by the model matches the observed data very well. Considering the hydrodynamic model was setup with average flow, while the dye study was conducted on a specific day, the disparity between the model result and the observed data was determined reasonable and acceptable.

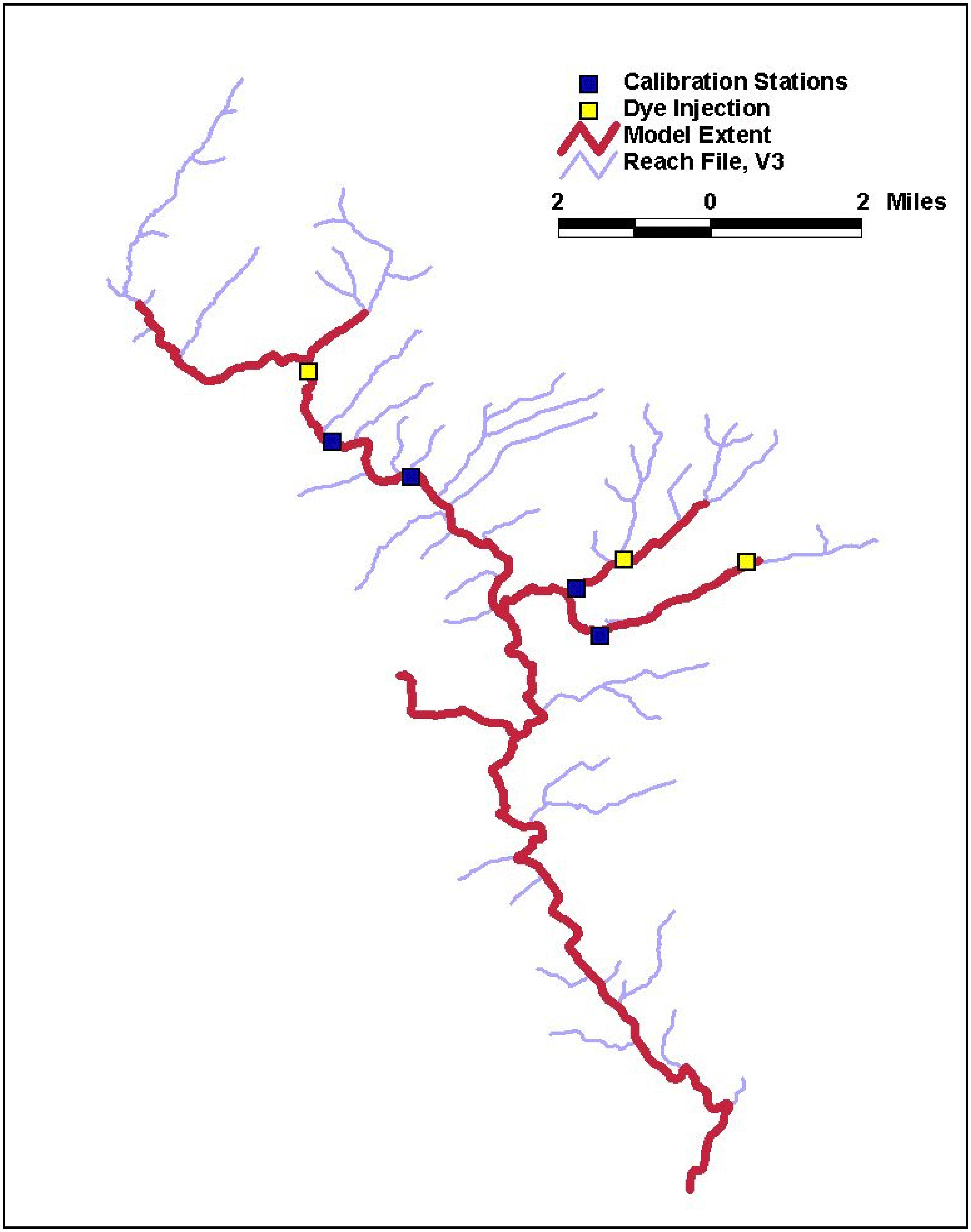

Figure D-4. Time-of-travel stations used for hydrodynamic calibration

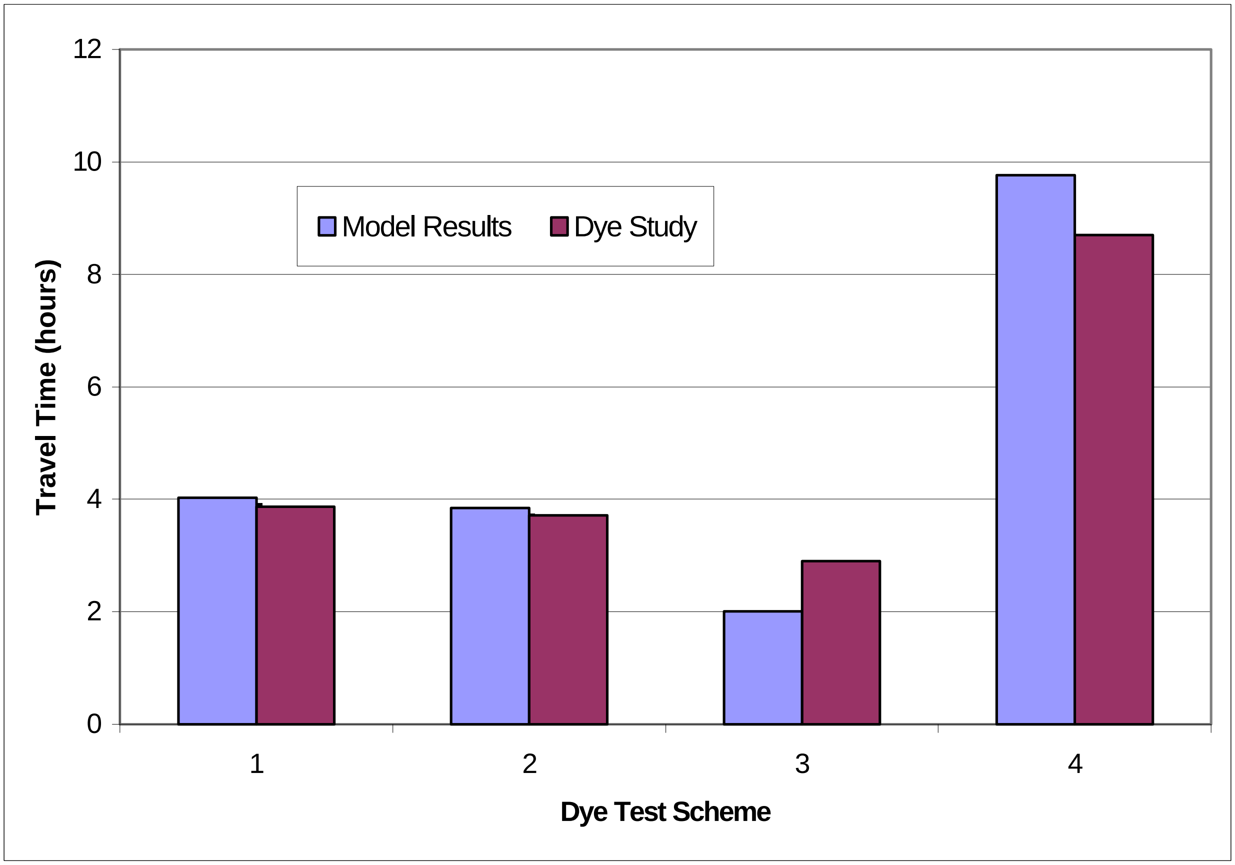

Figure D-5 Hydrodynamic Calibration Results

D.4.2 Water Quality Model

This section outlines the configuration and calibration of the WASP model used for water quality modeling of the Wissahickon Creek basin.

D.4.2.a Segment Mapping

115 one-dimensional WASP segments were obtained from the same number of EFDC grids using a 1-to-1 direct mapping technique. Since sediment processes were not explicitly simulated in this study, a single artificial benthic segment was assigned below all of the 115 water column segments.

D.4.2.b Boundary Conditions

Boundary conditions in the WASP/EUTRO model framework were represented as water quality constituent concentrations in inflow water. The locations for boundary conditions were determined as the points with significant inflows as well at the downstream mouth of Wissahickon Creek. The downstream boundary condition had no effect on the water quality dynamics, and only served to satisfy the format requirement of WASP. Based on the flow balance calculation, 20 locations for boundary conditions were identified at the five upstream segment (Wissahickon Creek, Trewellyn Creek, Pine Run, Sandy Run, and Lorraine Run), the effluent points at five major point source dischargers (North Wales WWTP, Upper Gywnedd WWTP, Ambler WWTP, Upper Dublin WWTP, and Abington WWTP), and the confluence points of Wissahickon Creek with ten minor tributaries.

Nine constituents are included as state variables in the water quality model, thus the boundary conditions included the concentrations of all the nine constituents. Since periphyton is not transportable, the concentration is specified as 0.0 for all the 20 boundary conditions. As for chlorophyll-a, the concentration is specified as 0.0 for the five major point sources, and a background concentration of 0.5 ug/L was specified for the other 15 boundary conditions. The concentrations of ammonia, nitrate/nitrite, ortho-phosphate, CBODu, and DO for the point sources were specified based on the data provided by the dischargers. Since no data are available for the two organic constituents: organic-N and organic-P, a background concentration of 0.1 mg/L is specified. The concentration boundary conditions for the other 15 locations were determined through an iterative process, which firstly provides an initial estimate based on available monitoring data, and then adjusts the estimated value through the calibration process to obtain a refined estimation.

D.4.2.c Other forcing functions

The nutrient load from ten minor point sources were configured as dry point source loads in the model input file. Dry loads were specified instead of boundary condition to represent these forcing function because flow from these dischargers was negligable and did not affect hydrodynamics. Therefore, it was not necessary to include these discharges in the hydrodynamic model, hence treating the load as boundary conditions.

Since the model is configured to simulate low flow condition, non-point source load does not contribute any significant impact to the system. Therefore, no specific non-point source loads were configured.

D.4.2.d Calibration

The model configured with proper boundary conditions and forcing functions was run through a 80 day period to allow the model reach steady state. Figure D-6 shows the dynamic process of the model reaching steady state. The fluctuation of DO concentration as displayed in this figure indicates the diurnal DO variation due to biological activities of micro- and macro-algaes.

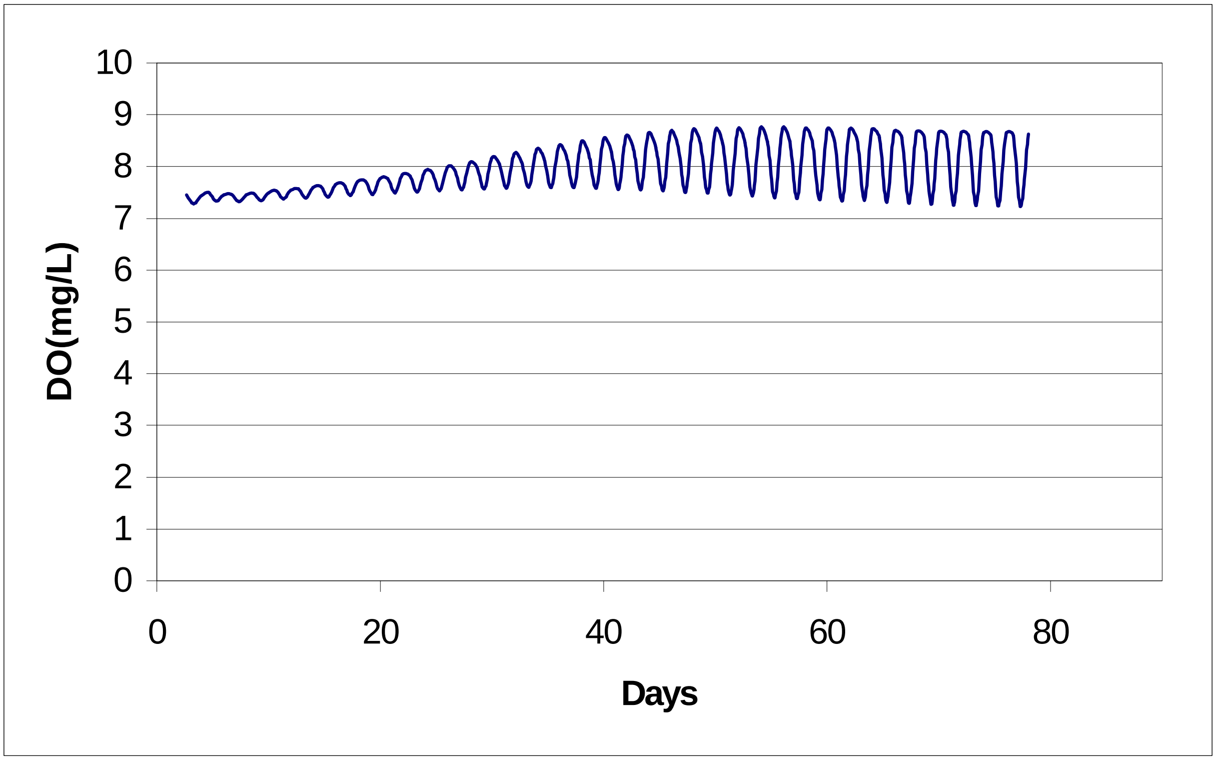

Figure D-6. Dynamic Process for Reaching Steady State DO

The diurnal fluctuation of DO concentration has strong environmental implications. Most eutrophication models only focused on daily average DO. This method works well when the biological activity in a water body is not significant, hence the daily DO fluctuation. However, in a highly biological active system, the DO sources and sinks generated by the biological processes could cause significant swings of DO concentration at different time of a day. In this case, daily average DO is no longer a single valid environmental indicator for oxygen conditions in the waterbody. For example, assume a daily average DO of 5.5 mg/L in such a waterbody, the daily minimum DO could reach as low as 2 or 3 mg/L by the respiration of algae during the dark period, causing undesired ecological consequence such as fish killing in some fish culturing waterbodies. Therefore, a model capable of simulating diurnal DO variation was preferred over the previous approach. As shown in Figure D-6, the WASP/EUTRO model enhanced in this study was equipped with this capability, which allowed simulation of more realistic and useful information for environmental decision making regarding the DO impairment in the Wissahickon Creek basin.

The model was calibrated using the observed data during the low flow survey period of 2002. The major parameters subjected to calibration included algal and periphyton growth rates, respiration rate, death rate, CBOD decay rate, sediment oxygen demand (SOD), nitrification and denification rates, nitrogen and phosphorus recycling rate from dead algae, and carrying capacity of periphyton. The calibration process was continued until the model reproduced the observed data well. Figures D-7 to D-18 show the comparison of model results against observed data. In general, the model reproduced the spatial distribution of water quality very well. Specifically, the model mimicked the response of water quality to the loading from point source dischargers in that, where point sources enter the system, the concentration of the corresponding constituents matched observed conditions downstream of the discharge points. In addition, the DO fluctuation as simulated with the diurnal module in the enhanced model code matched the observed data reasonably well. Although there is no data indicating the distribution of periphyton in the Wissahickon Creek system, the good performance of the model in mimicking the DO variation suggests that the model achieved a reasonably good performance in simulating the periphyton processes. This calibrated model could thus be configured using designed conditions to predict the water quality response in the modeled system to different discharge and management schemes, thereby providing environmental decision makers quantitative guidance for formulating technically sound management scenarios.

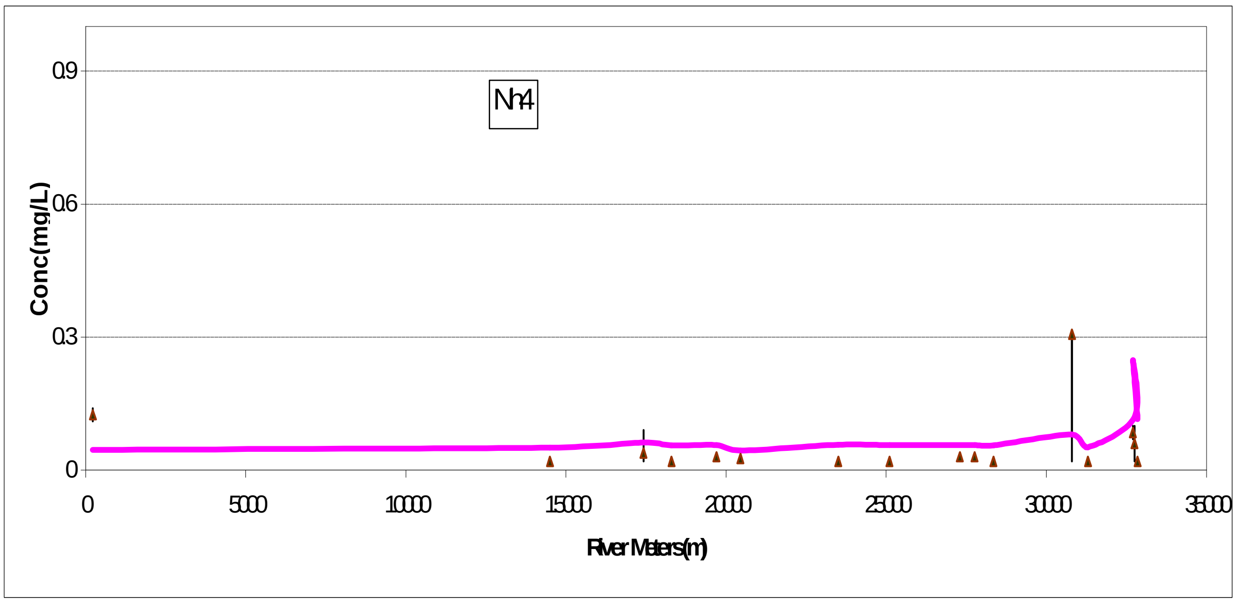

Figure D-7 Model Calibration of NH3 for Wissahickon Creek

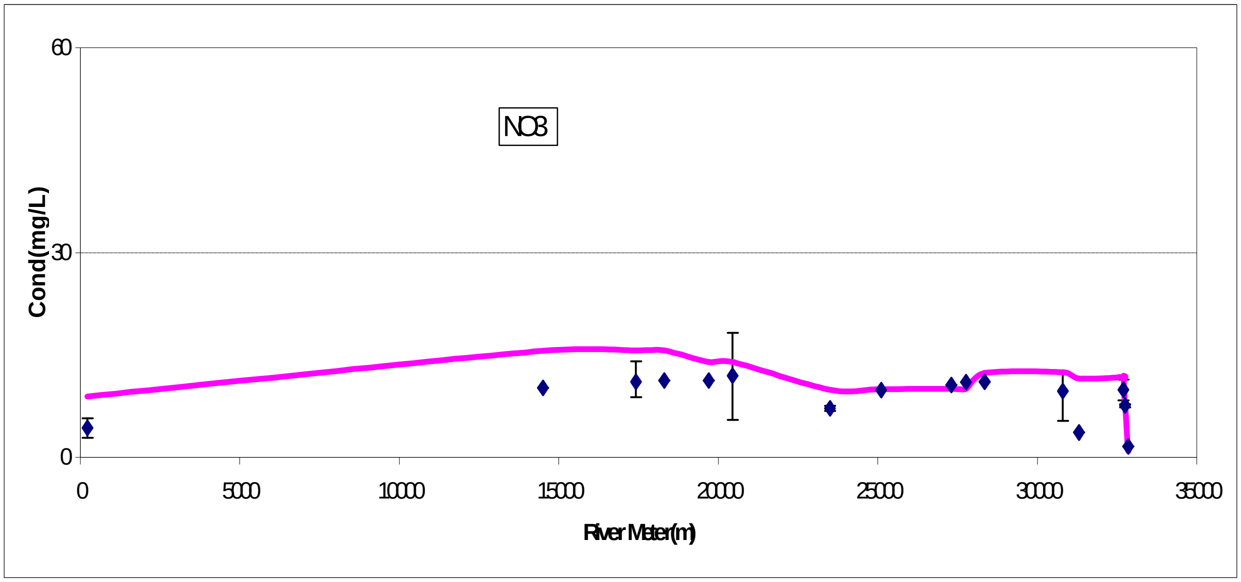

Figure D-8 Model Calibration of NO3 for Wissahickon Creek

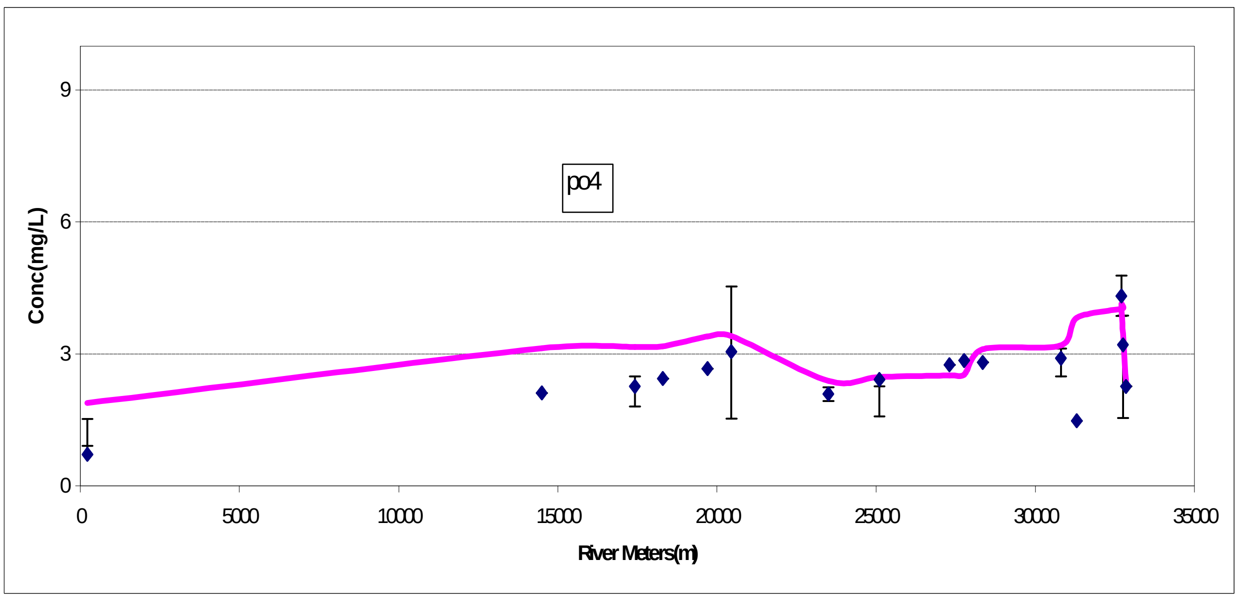

Figure D-9 Model Calibration of ortho-PO4 for Wissahickon Creek

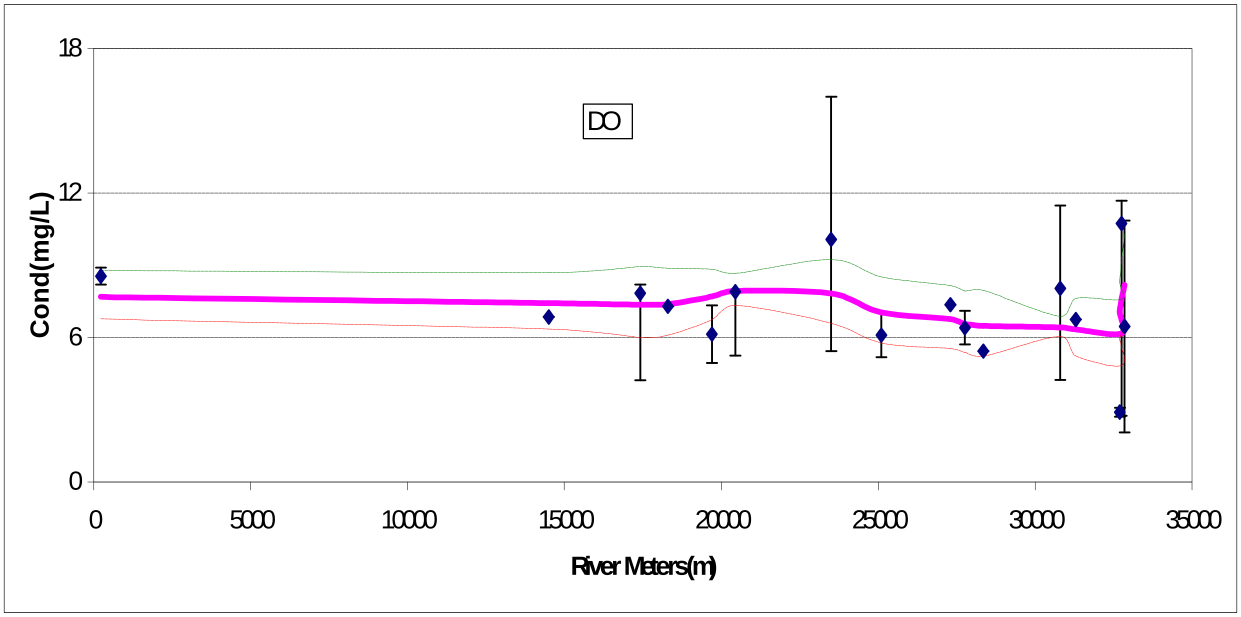

Figure D-10 Model Calibration of DO for Wissahickon Creek (bars represent ranges of observed data resulting from diurnal variations; dotted lines are model-predicted diurnal ranges)

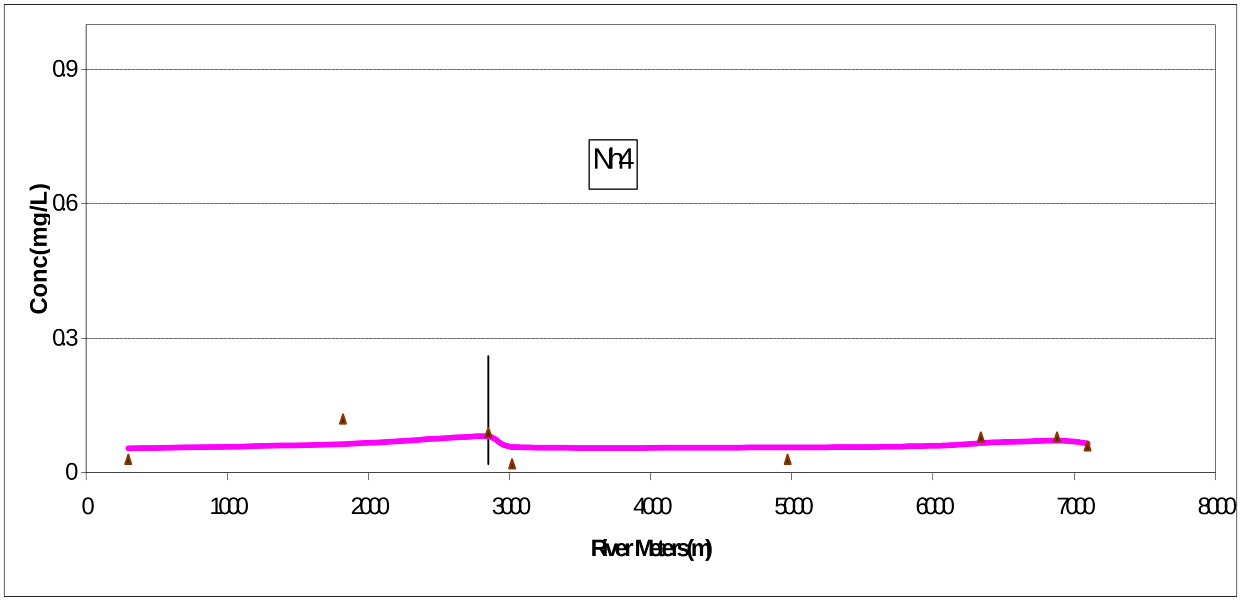

Figure D-11 Model Calibration of NH4 for Sandy Run

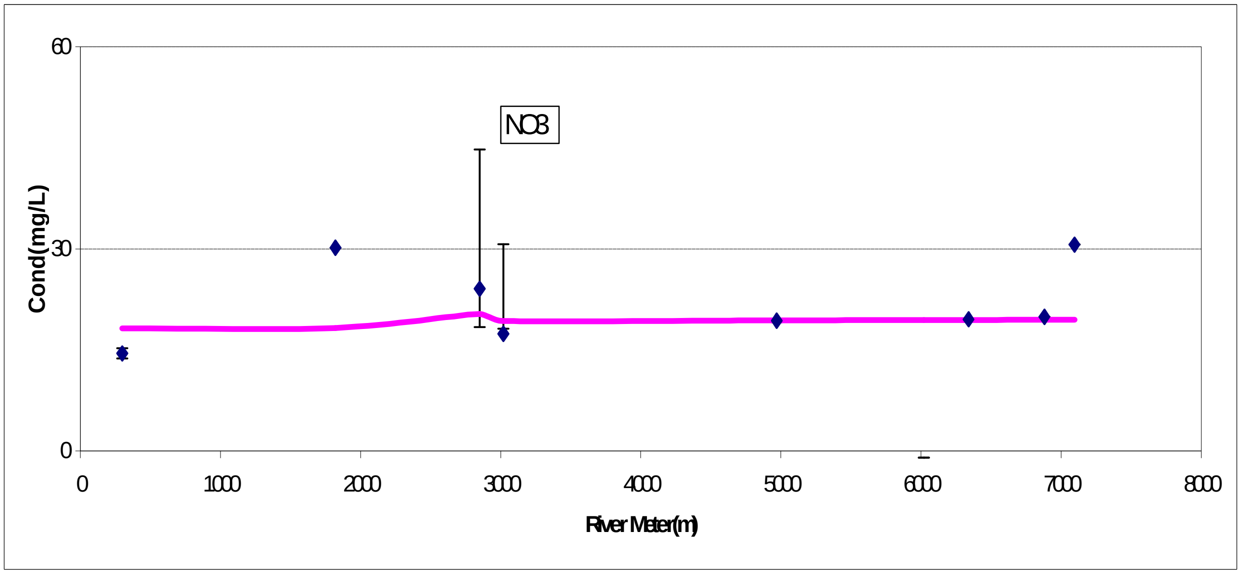

Figure D-12 Model Calibration of NO3 for Sandy Run

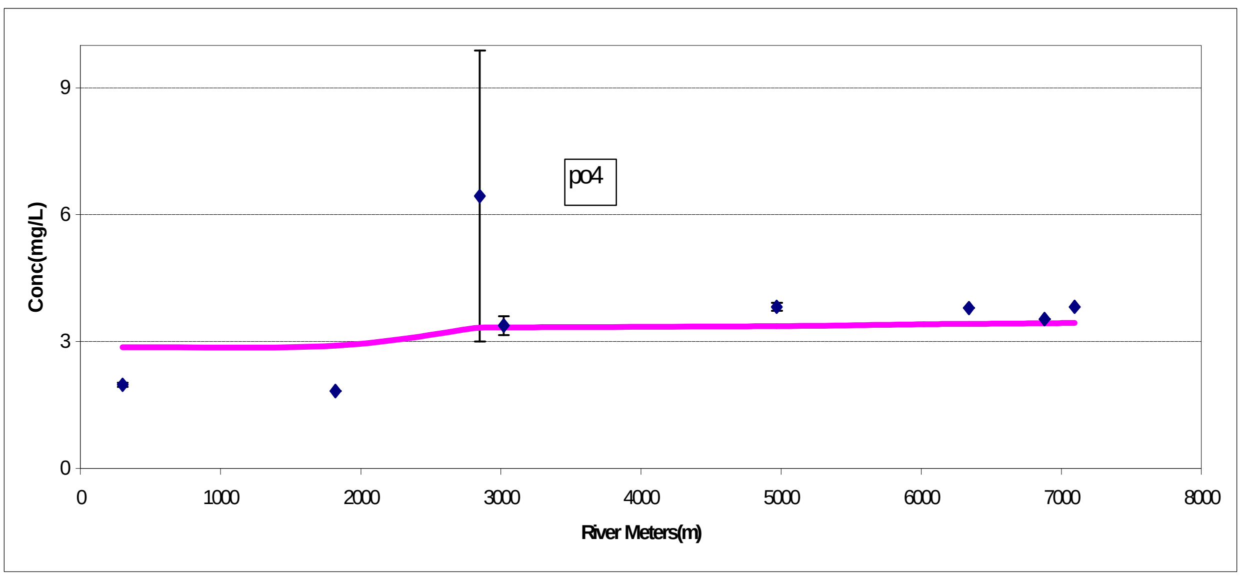

Figure D-13 Model Calibration of PO4 for Sandy Run

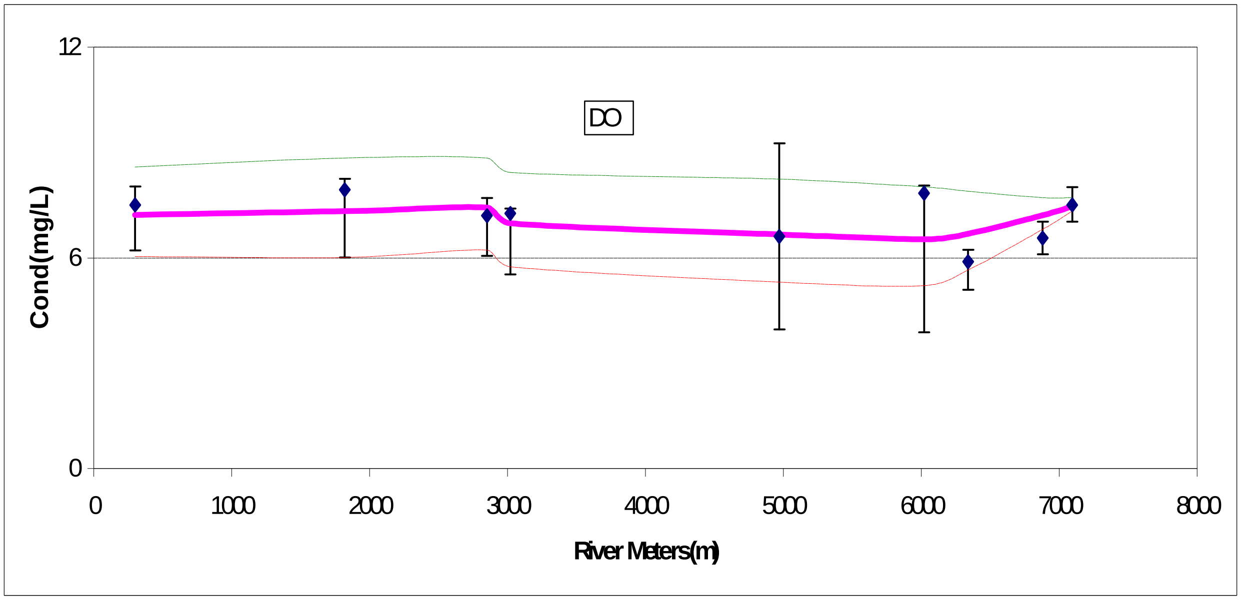

Figure D-14 Model Calibration of DO for Sandy Run (bars represent ranges of observed data resulting from diurnal variation; dotted lines are model-predicted diurnal ranges)

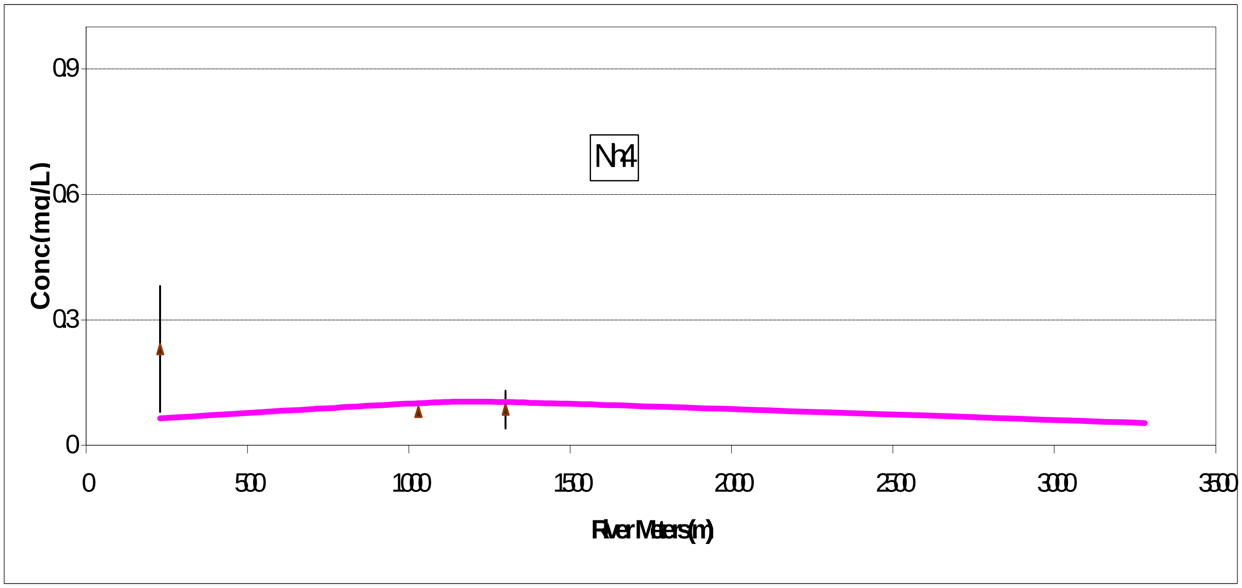

Figure D-15 Model Calibration of NH4 for Pine Run

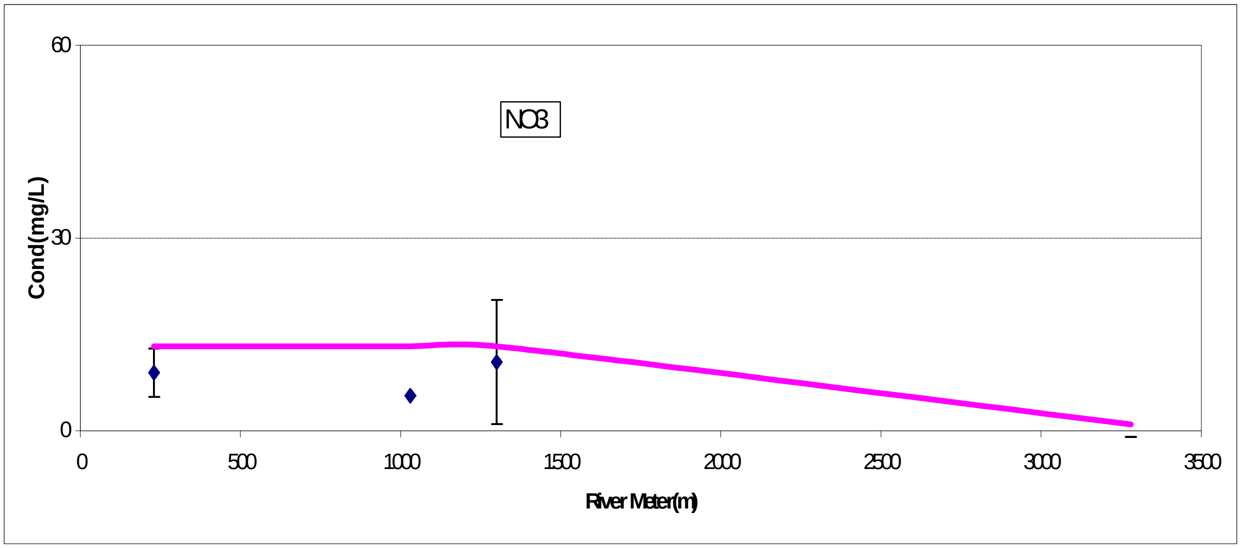

Figure D-16 Model Calibration of NO3 for Pine Run

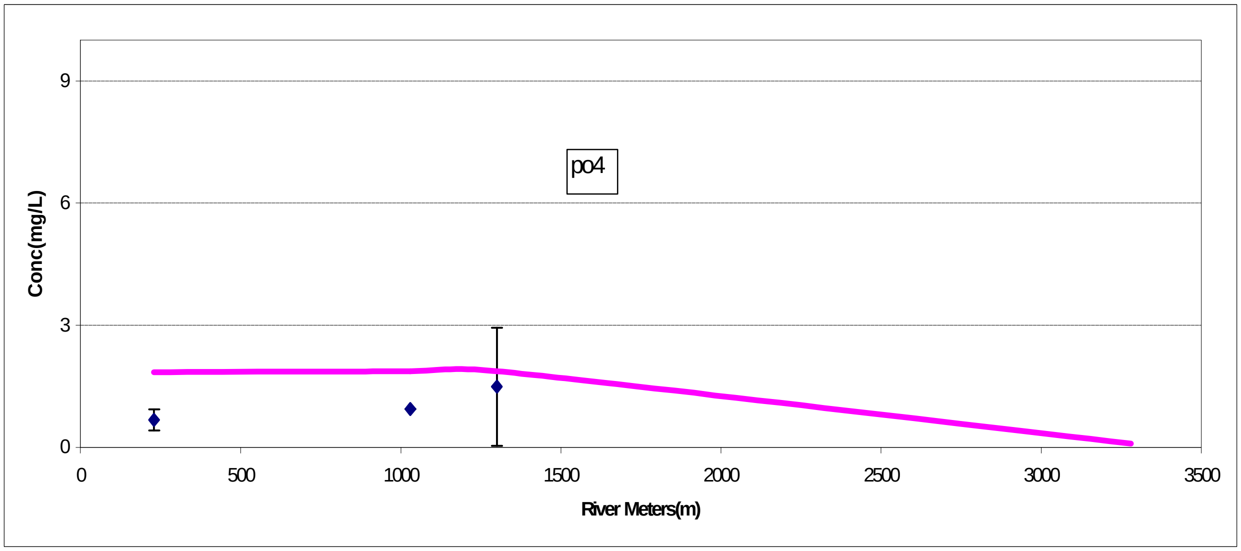

Figure D-17 Model Calibration of ortho-PO4 for Pine Run

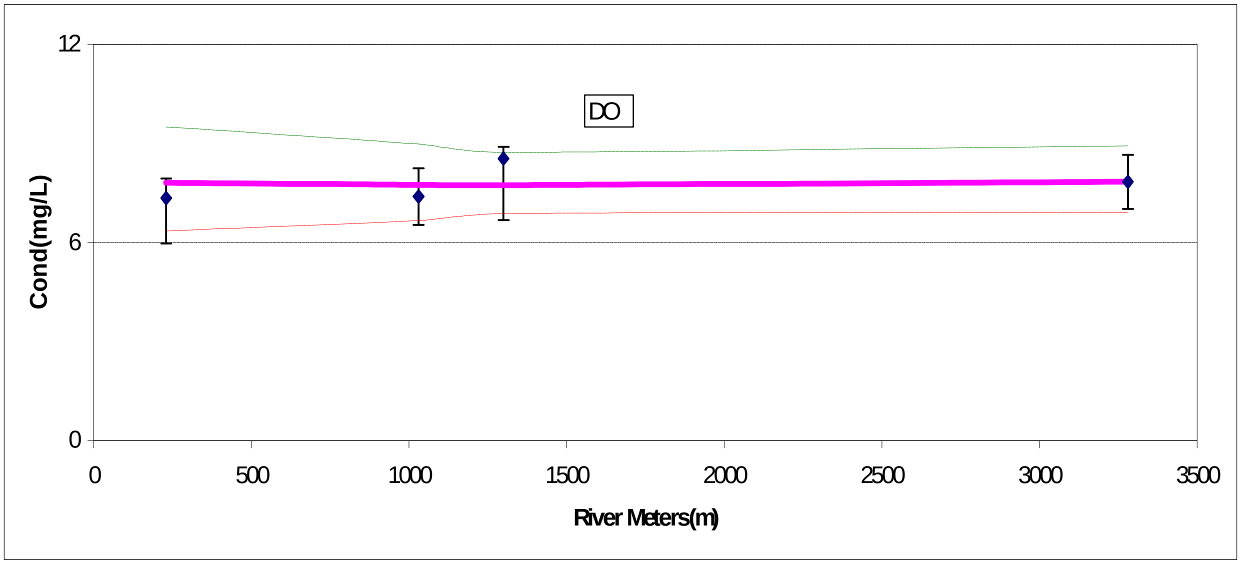

Figure D-18 Model Calibration for DO for Pine Run (bars represent ranges of observed data resulting from diurnal variations; dotted lines are model-predicted diurnal ranges)

D.4.3 Sensitivity of Discharge Flow

The Wissahickon hydrodynamic and water quality model was developed using average flow from the dischargers. However, since the discharge flows showed temporal variations, it was determined necessary to analyze the sensitivity of varying discharger flows on the simulated DO concentration.

Two scenarios were analyzed: (1) increased discharges by a factor of 1.5, and (2) reduced discharges by a factor of 0.5. The EFDC hydrodynamic model was updated with the varied flows and was run to generate an updated hydrodynamic file. The water quality model was then run with the updated hydrodynamic information. The resulting DO concentrations under these two scenarios were compared to the calibrated model using average discharges. The relative sensitivity of DO concentrations to the discharger flow are shown in Figures D-19 and D-20 in terms of deviation from results using average flows. The results show that DO concentration has very small sensitivity to the variation of flows tested. Therefore, it is considered reasonable to use the average flow to drive the steady state model, without sacrificing model accuracy in predicting DO response.

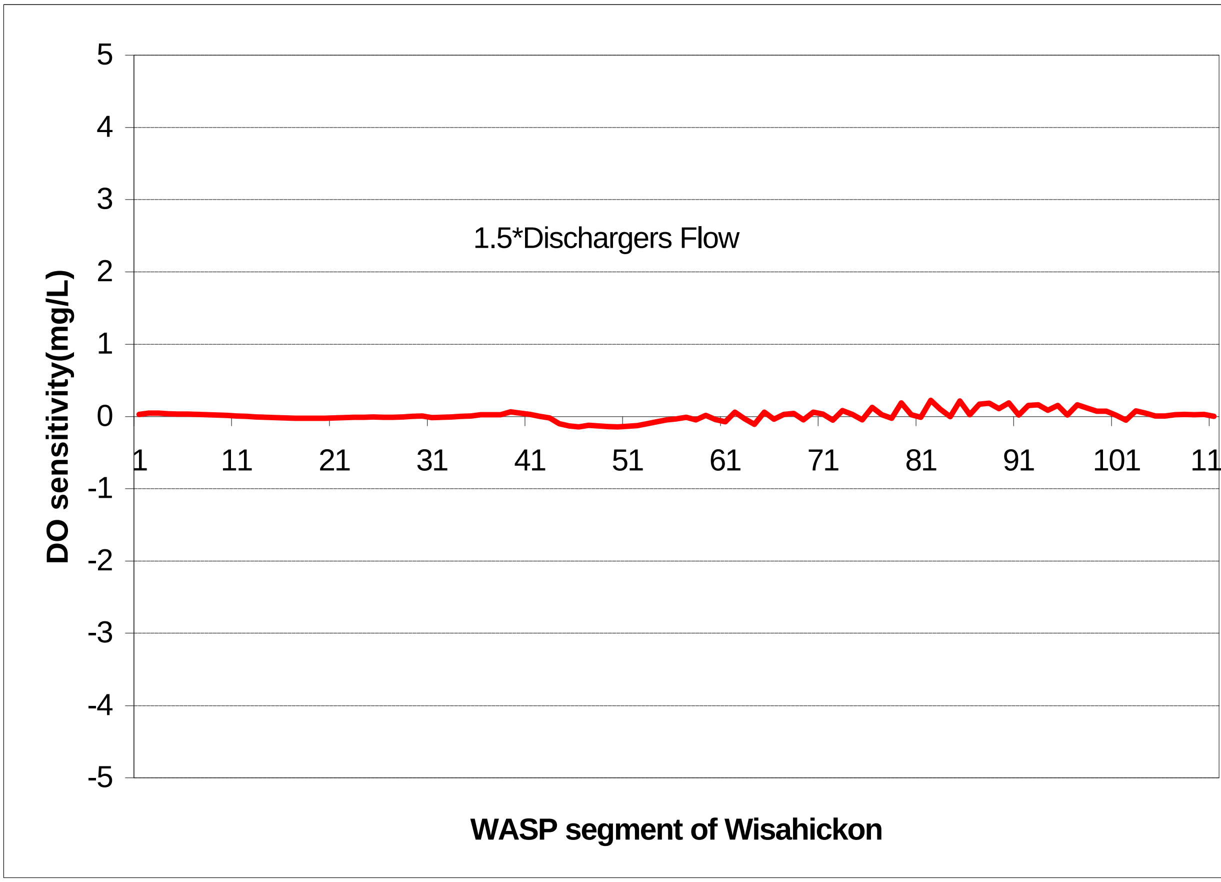

Figure D-19 DO Sensitivity to Dischargers Flow (Case 1)

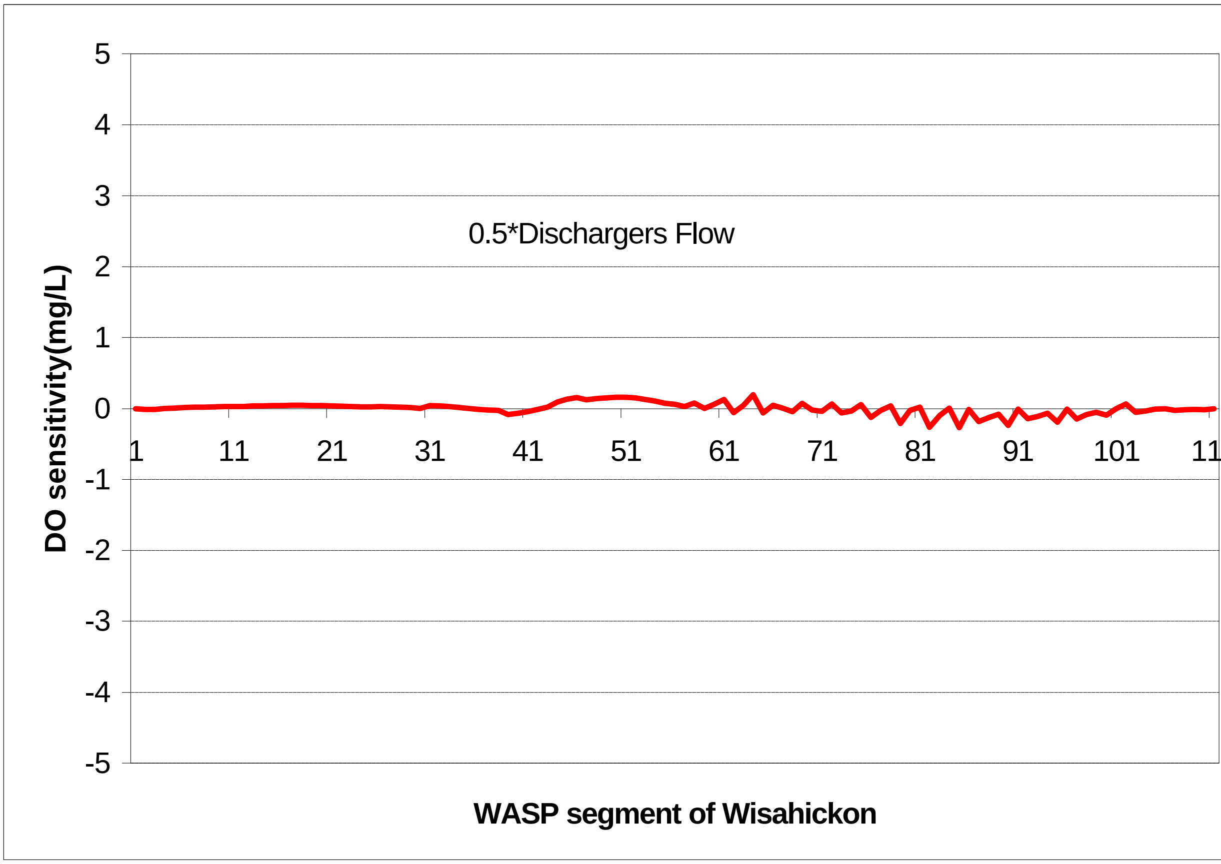

Figure D-20 DO Sensitivity to Dischargers Flow (Case 2)

D.5 TMDL Development

D.5.1 Critical Low Flow Condition

The critical condition for DO impairment in Wisahickon Creek system is the summer low flow condition. A standard flow often utilized for low-flow, steady-state analysis is the 7Q10 flow, defined as the streamflow that occurs over 7 consecutive days and has a 10-year recurrence interval, or 1 in 10 chance of occurring in any given year. Daily stream-flows in the 7Q10 range are general indicators of prevalent drought conditions which normally cover large areas. The 7Q10 flow calculated at the mouth (USGS gage 01474000) was 16.26 cfs. This 7Q10 flow is usually extrapolated throughout the upstream and headwaters of a watershed to estimate a basin-wide, steady-state flow for the selected model. For TMDL development and waste load allocations, point sources are modeled at design flows provided for in their respective NPDES permits. However, when all point sources in the Wissahickon Creek basin are at design flows, the combined discharge from point sources is 27.9 cfs, exceeding the 7Q10 flow at the mouth. Since average flows from dischargers are inherently included in the flow budget of Wissahickon Creek through the historical record used for the statistical determination of the 7Q10 flow, this low flow was not determined to define the assimilative capacity of the stream accurately as discharge flows are increased to their design capacity. Therefore, background flows (streamflow without discharge contributions) for Wissahickon Creek were estimated for 7Q10 flow conditions by subtracting average discharge flows recorded during the critical summer period of 2002 (combined flow of 14.9 cfs) from the 7Q10 at the mouth (16.3 cfs). The remaining 1.4 cfs of background flow in Wissahickon Creek was distributed throughout the watershed using ratios established in the flow budget for hydrodynamic model configuration. Although expected to be accounted for in the determination of background flows during 7Q10 conditions, after discharges were removed from consideration and 7Q10 flows were distributed to headwaters, the remaining 1.0 cfs did not account for flows from Coorson’s Quarry (historical average of 12.5 cfs). Under drought conditions, much of the Wissahickon Creek flow is therefore considered lost to groundwater before reaching the mouth. To accurately simulate the benefits that occur through dilution of Wissahickon Creek streamflows with flows from the quarry, the average of 12.5 cfs was added to Lorraine Run in addition to the background 7Q10 flows distributed throughout the watershed. Once the background 7Q10 flows and quarry flows were configured in the model, discharge flows were added at design flows. The resulting total flow at the mouth of Wissahickon Creek for the critical low-flow conditions was 40.8 cfs.

D.5.2 Critical Discharge Condition and DO Prediction

The critical discharge condition is so defined such that all point sources discharge at designed flow rates and constituent concentrations specified by NPDES permits, while the flow condition is at 7Q10 critical low flow. The water quality consequence of dissolved oxygen is simulated using the hydrodynamic and water quality model developed as described in previous sections. As the first step, the 7Q10 baseflow and point sources design flows were incorporated into the EFDC hydrodynamic model to generate an updated hydrodynamic file. Then the calibrated WASP/EUTRO water quality model was updated with the new discharge concentration from the point source dischargers. The updated hydrodynamic file is used to provide corresponding critical transport force for the water quality model. The updated water quality model was again run for 80 days, and the resulting steady state spatial distribution of DO conditions are plotted in Figures D-21 through D-25. Note in these figures, the dashed lines represent daily average DO, and the solid lines represent daily minimum DO.

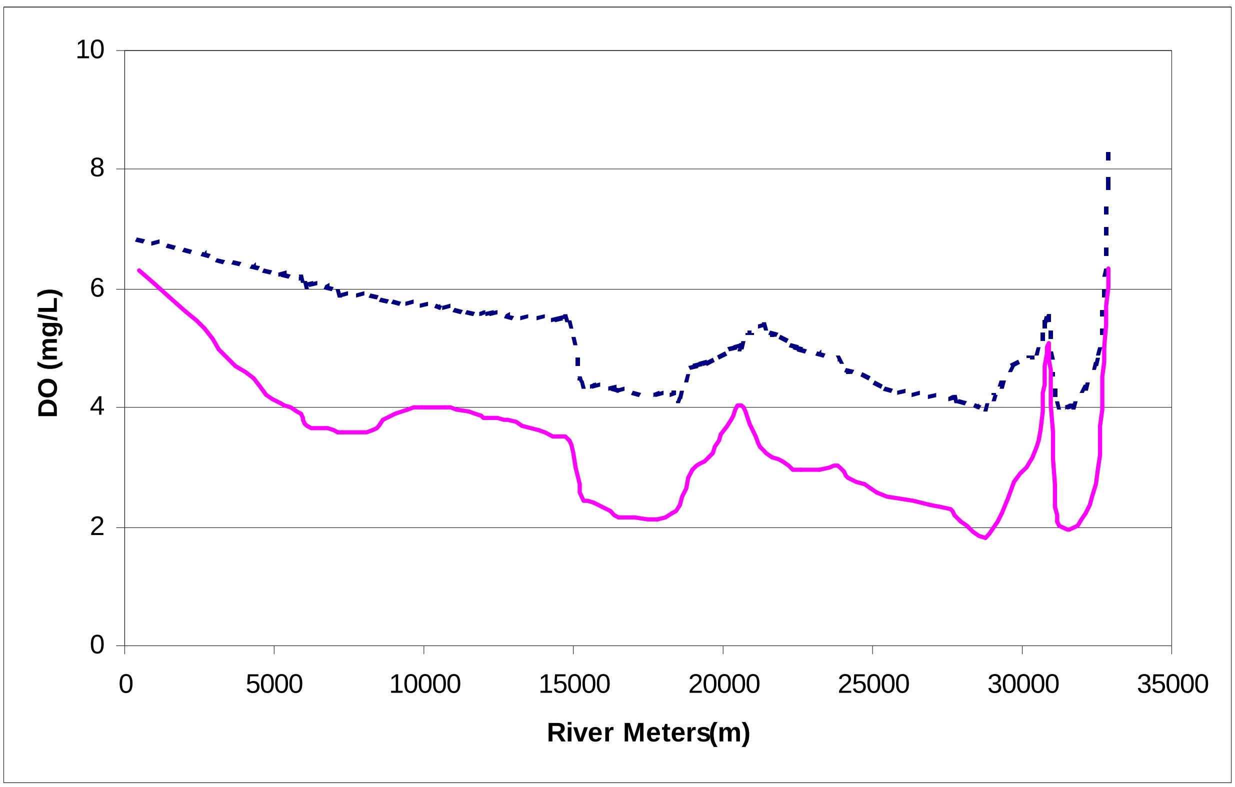

Figure D-21. DO concentration in Wisahickon Creek at critical conditions

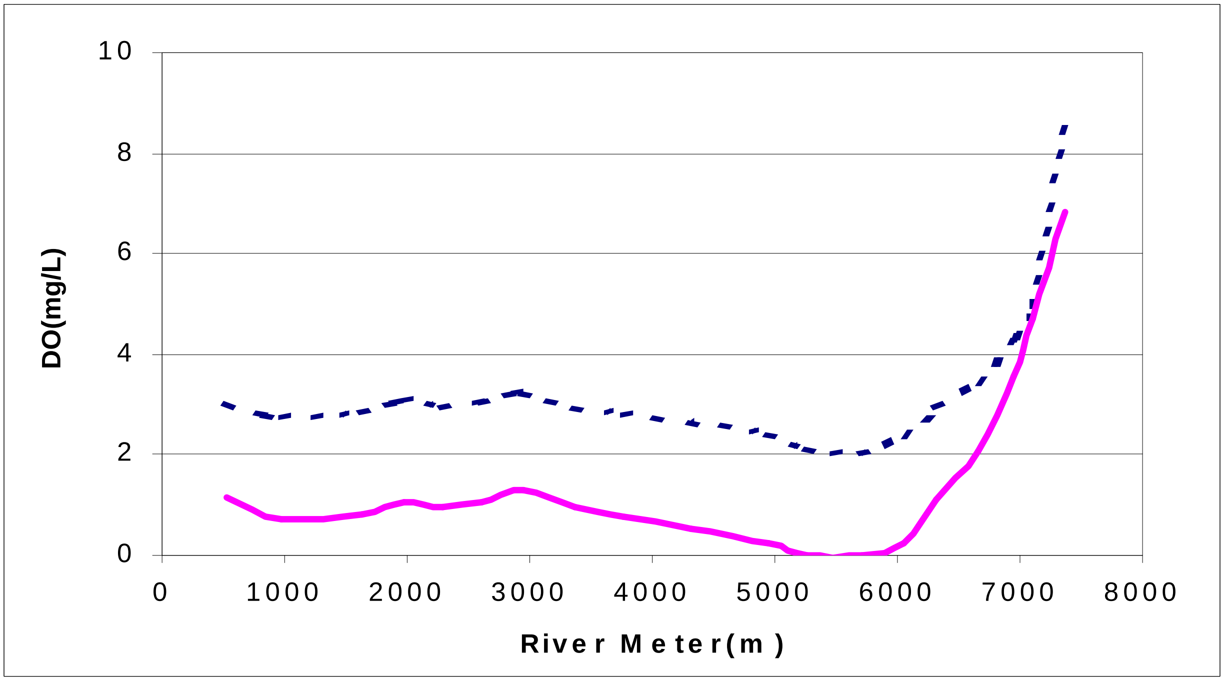

Figure D-22. DO concentration in Sandy Run at critical conditions

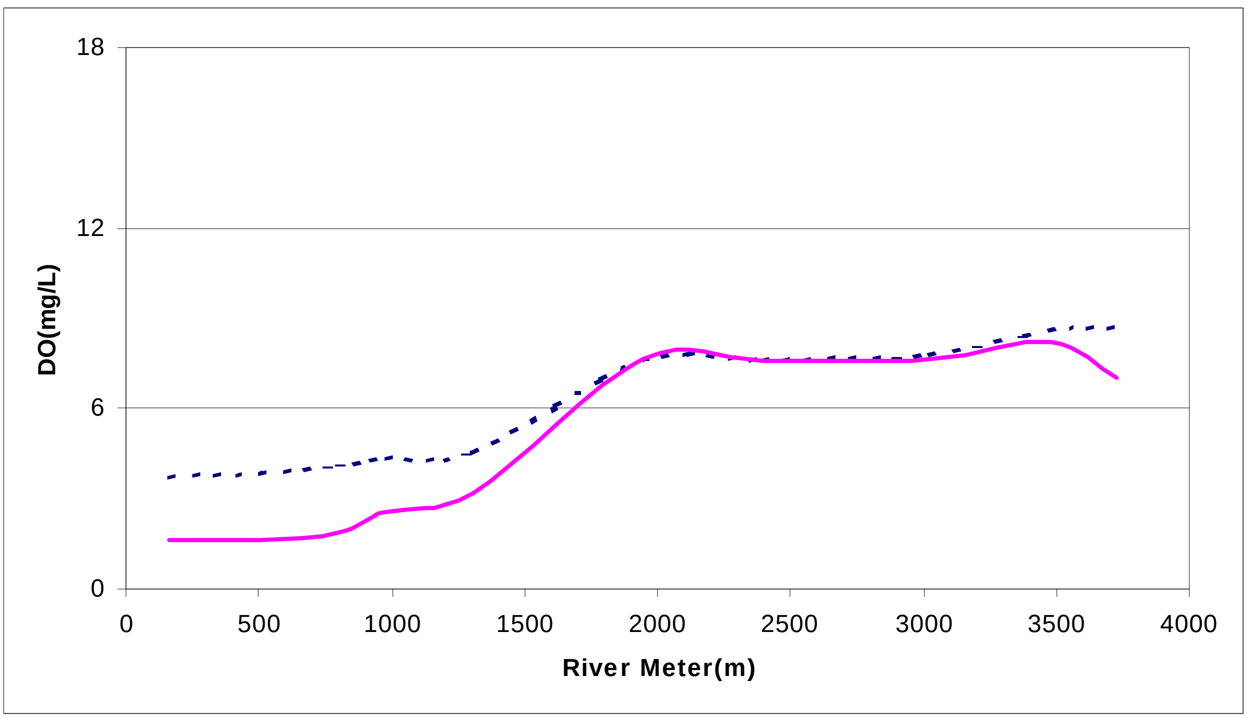

Figure D-23. DO concentration in Pine Run at critical conditions

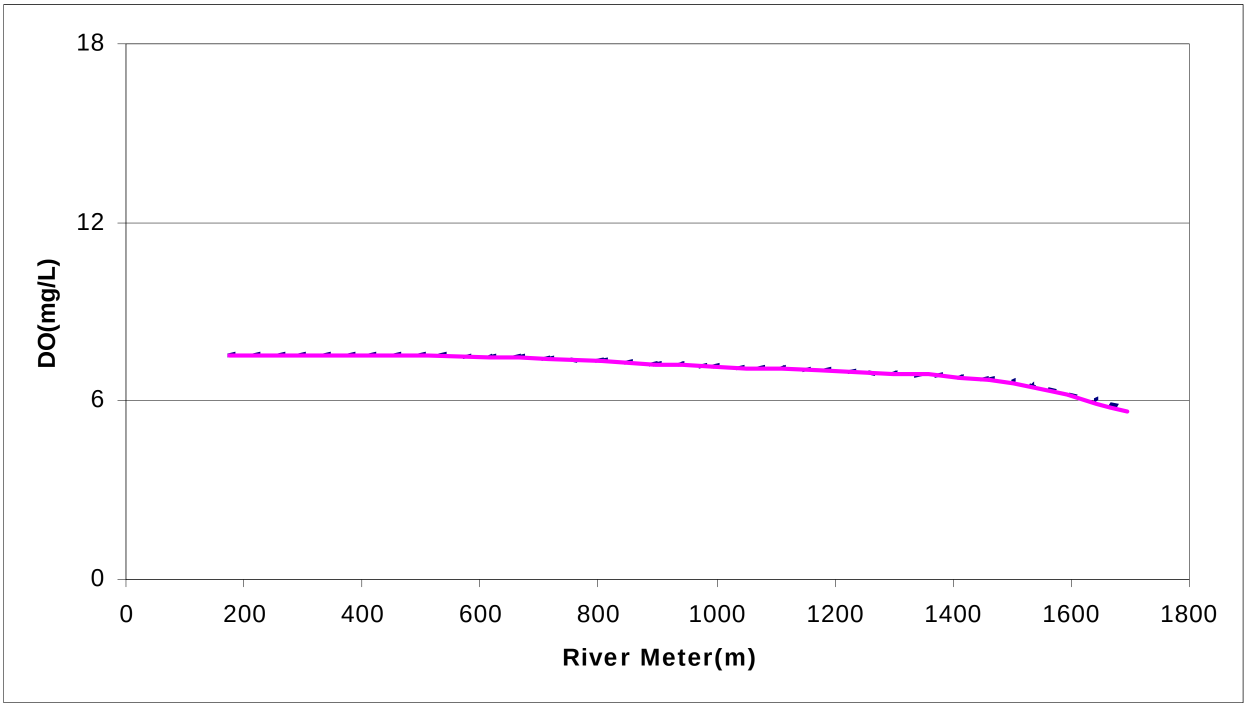

Figure D-24. DO concentration in Trewellyn Creek at critical conditions

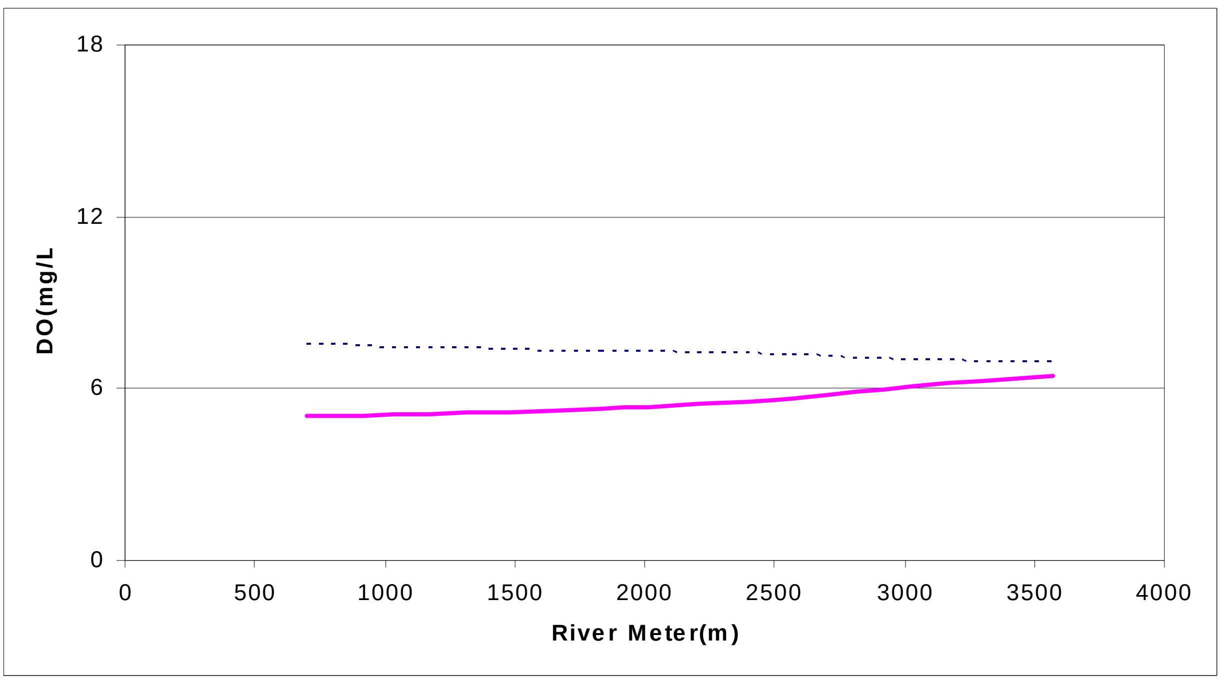

Figure D-25. DO concentration in Lorraine Run at critical conditions

As shown in Figure D-21 through D-25, the DO concentrations in Wissahickon Creek, Sandy Run, and Pine Run were very low under the critical condition. According to the water quality standard, the daily average DO should be above 6.0 mg/L, and the daily minimum DO should be above 5.0 mg/L. Compared to this standard, Wissahickon Creek, Sandy Run creek, and Pine Run Creek were seriously impaired in terms of DO when point source discharge at design flow and concentration under critical flow conditions. Therefore, it was necessary to implement load reductions in order to satisfy water quality standards.

D.5.3 Two Alternatives Proposed by the Dischargers

Two alternatives were proposed by stakeholders to relieve DO problems under critical condition: (1) increase the discharge DO concentration by 1 mg/L for each of the 5 major dischargers, and (2) fix the ortho-phosphate concentration at 2.0 mg/L in the effluent. Both alternatives were tested using the water quality model. Results for alternative 1 are shown in Figures D-26 through D-28. Results for alternative 2 are shown in Figures D-29 through D-31. Although the two alternatives have improved the DO condition, the resulting DO concentrations still cannot satisfy the water quality standard, suggesting further load reduction is necessary. As with previous figure, the dashed lines represent daily average DO, and the solid lines represent daily minimum DO.

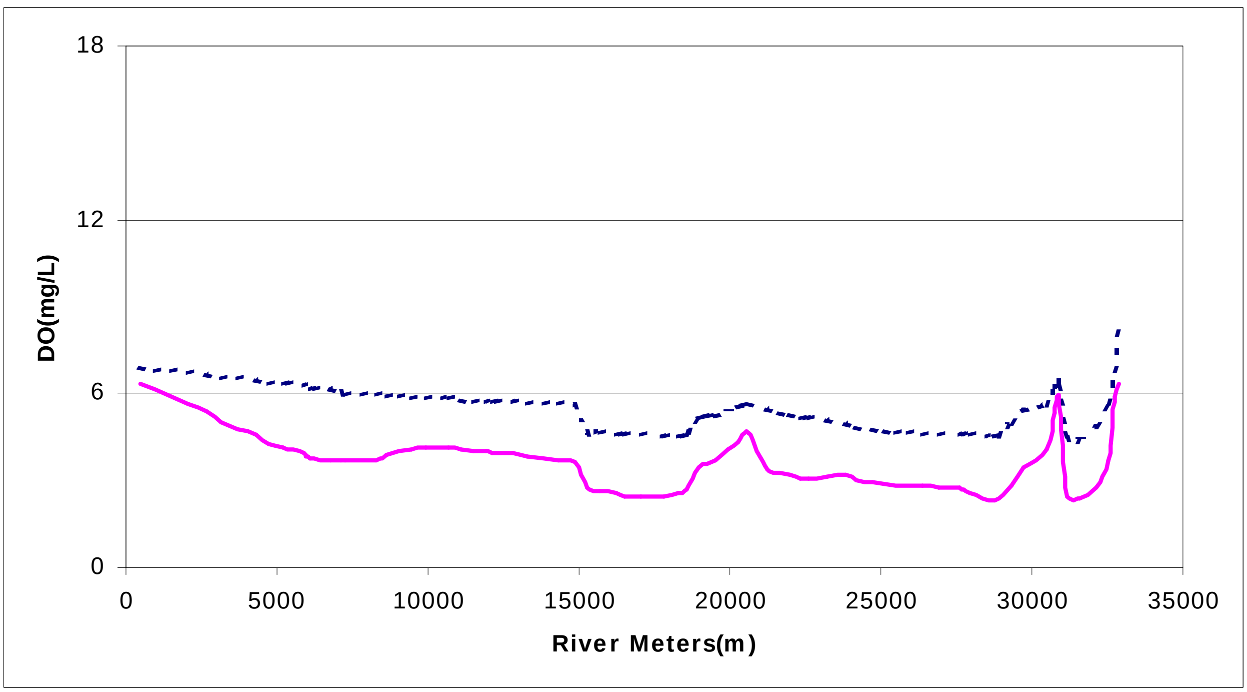

Figure D-26. DO concentration in Wisahickon Creek with alternative 1

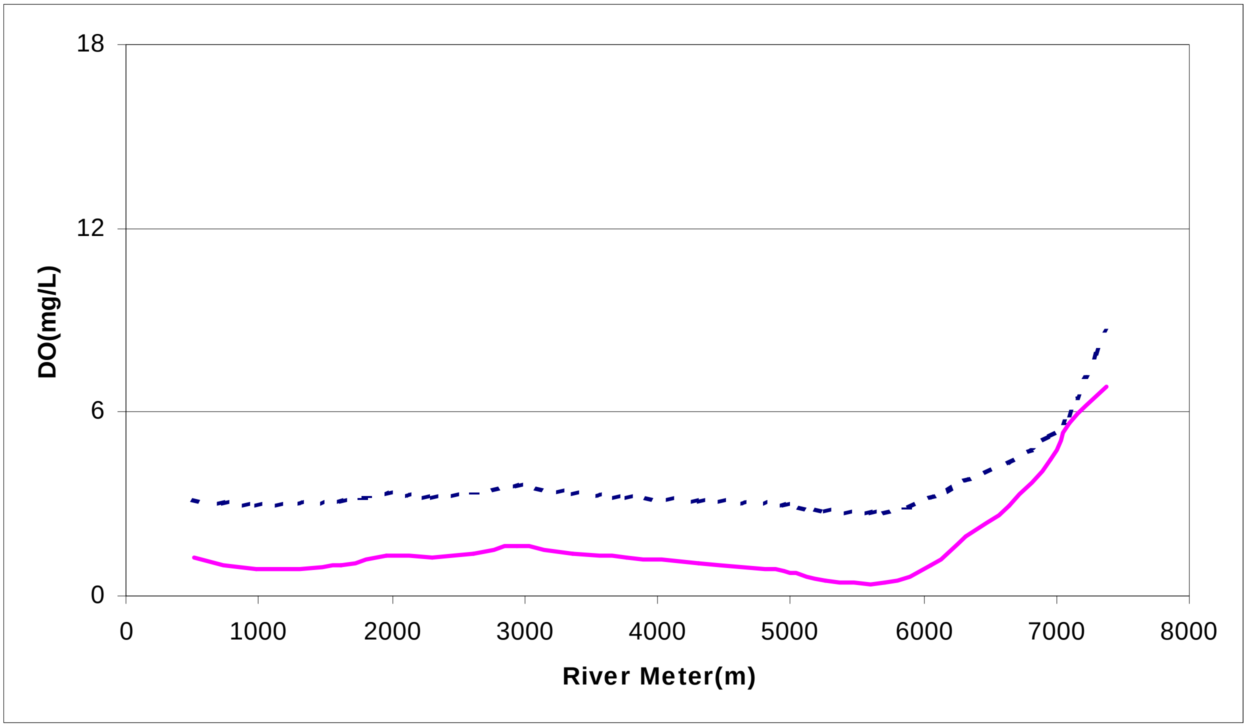

Figure D-27. DO concentration in Sandy Run with alternative 1

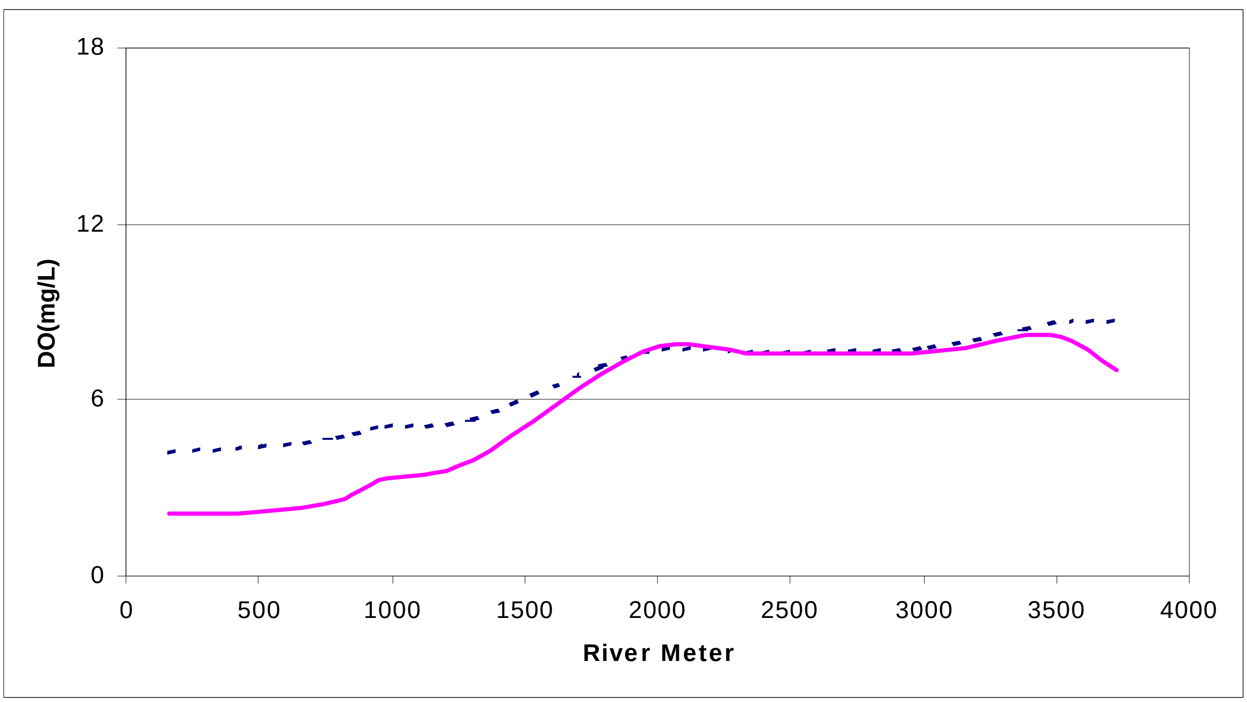

Figure D-28. DO concentration in Pine Run with alternative 1

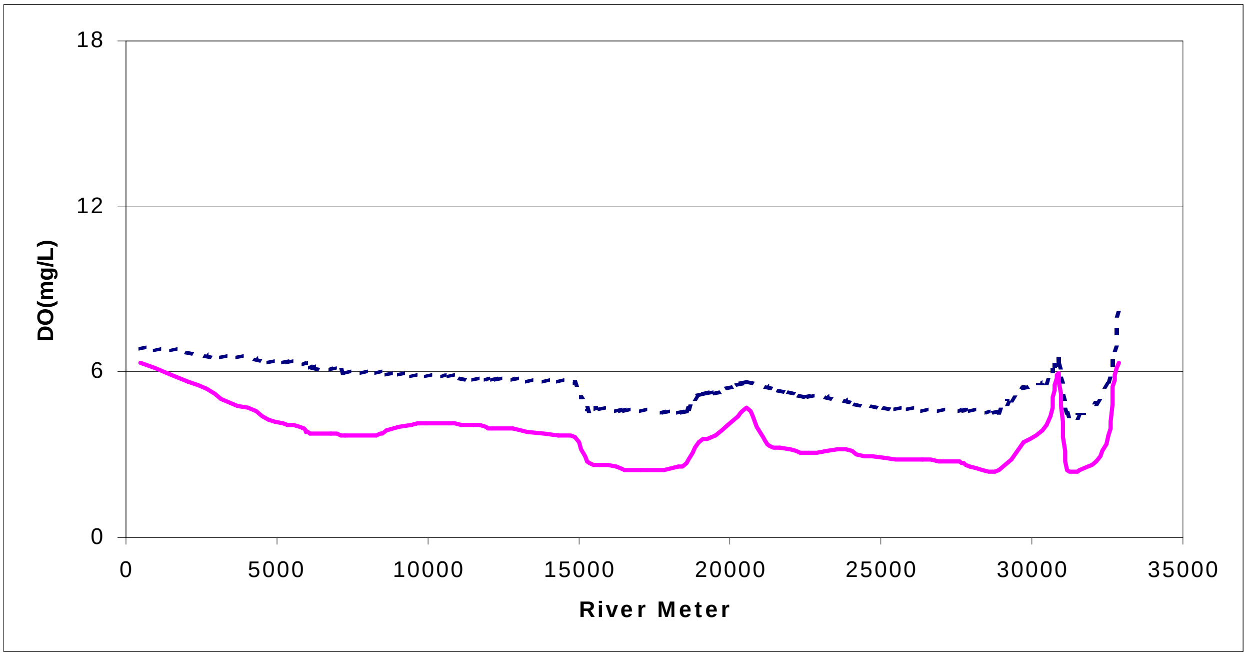

Figure D-29. DO concentration in Wisahickon Creek with alternative 2

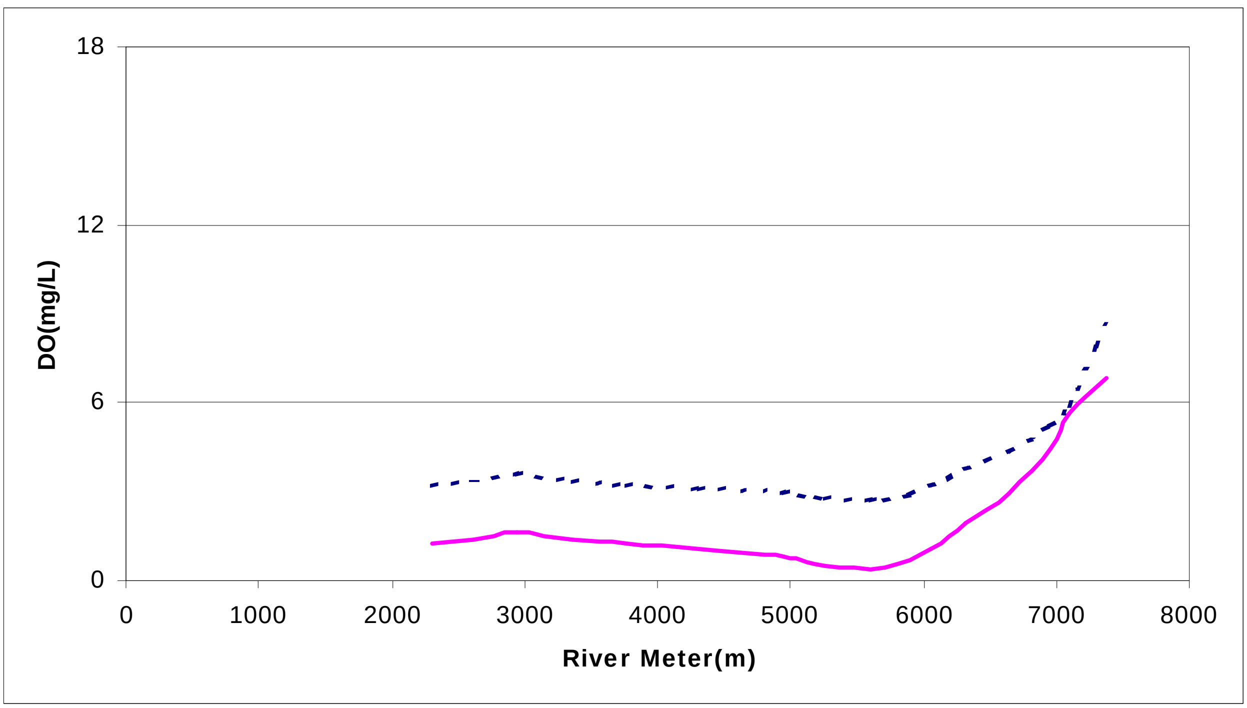

Figure D-30. DO concentration in Sandy with alternative 2

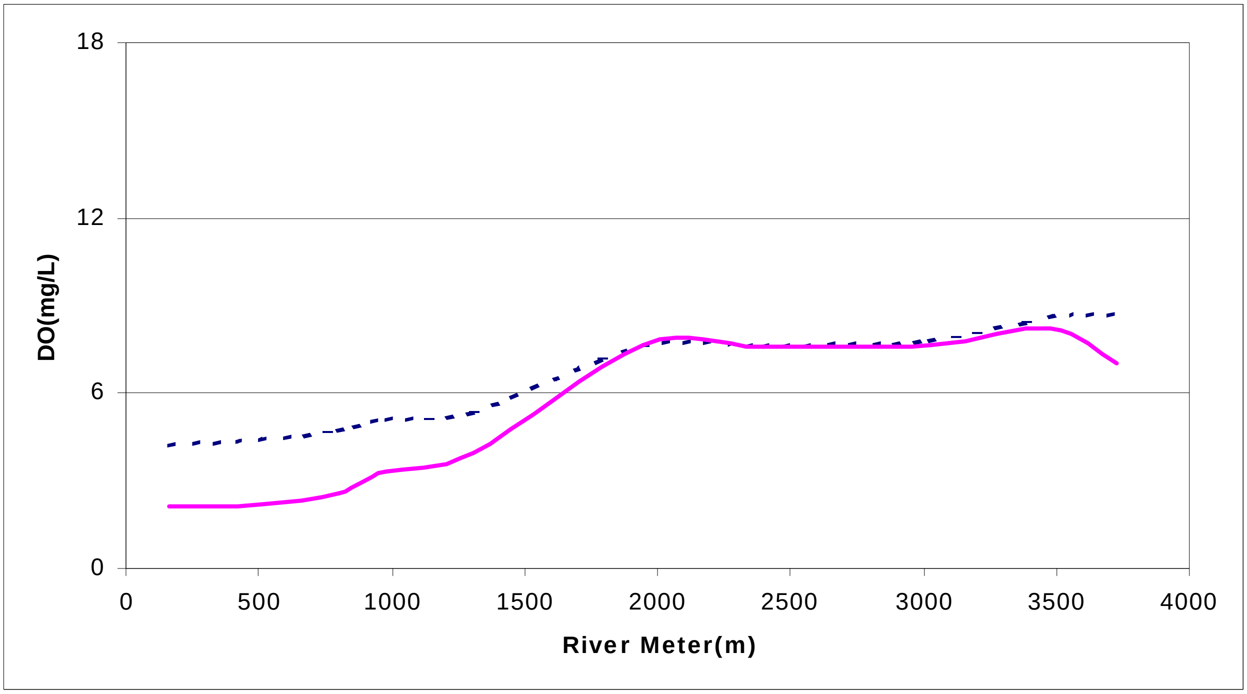

Figure D-31. DO concentration in Pine Run with alternative 2

D.5.4 Reduction Scenario and TMDL development

TMDLs were developed such that both the daily average and daily minimum DO was above water quality targets of 6.0 mg/L and 5.0 mg/L, respectively. The method of developing such a TMDL is described as:

Step 1. Determine a baseline condition. For this study, two baseline scenarios were modeled: (1) all major discharges with DO levels at 6.0 mg/L (includes recommended increases of Ambler Borough and Abington Township effluent DO from 5.0 mg/L to 6.0 mg/L), and (2) all major dischargers with DO levels at 7.0 mg/L (1 mg/L above current or recommended levels);

Step 2. Run the water quality model, identify the location where problem DO concentrations occur;

Step 3. Reduce waste loads upstream of the locations identified as having DO problems;

Step 4. Evaluate the reduction scheme by running the updated model, then go to step 2 to identify new locations of minimum DO.

Repeat Step 2 to 4 until the minimum daily average DO is equal or above 6.0 mg/L, and minimum daily minimum DO is eqal or above 5.0 mg/L.

D.5.5 Benefit of Lorraine Run Flow

A model scenario was performed to test the effects of discontinuing flow from Coorson's Quarry into Lorraine Run. The flow from Lorraine Run creek was reduced from 12.5 cfs to 0.5 cfs for the TMDL reduction scheme. The affect of this scenario on the average daily DO concentration in Wissahickon Creek is shown in Figure D-32. For this figure, the dashed line represents the reduction scheme with quarry flows, and the red line represents conditions when the flow in Lorraine run is reduced to 0.5 cfs. Even with the TMDL reduction scheme, the DO concentration is predicted to violate the water quality standard at certain locations downstream of the confluence of Lorraine run if the 12.5 cfs of flow from Lorraine Run creek is reduced to 0.5 cfs. This result suggests that the quarry flow from Lorraine run has significant benefit to the water quality in Wissahickon Creek.

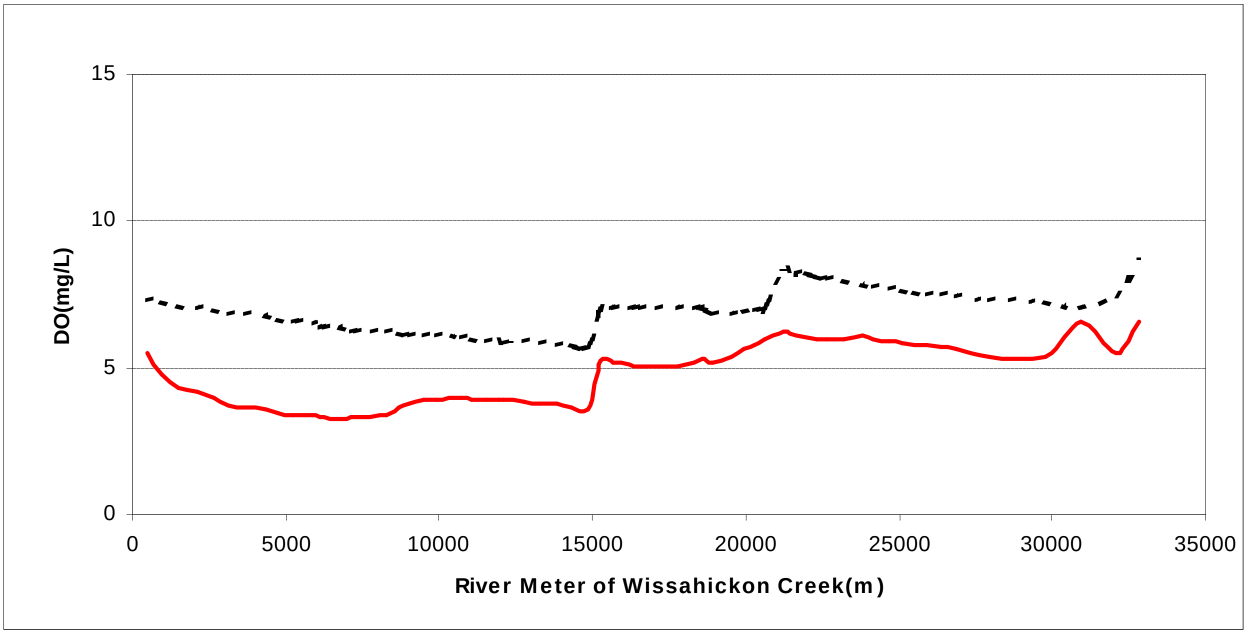

Figure D-32. Benefits of quarry discharge to Wissahickon Creek DO concentrations